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Reproductive Success of Black Skimmers on an Artificial Island: Effects of Hatching Date and Feeding Rate

Christopher Alan Gordon
College of William & Mary - Arts & Sciences

REPRODUCTIVE SUCCESS OF BLACK SKIMMERS ON AN ARTIFICIAL ISLAND: EFFECTS OF HATCHING DATE AND FEEDING RATE

A Thesis

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Master of Arts

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by

Christopher Alan Gordon

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

the requirements for the degree of

Master of Arts

Christopher Alan Gordon

Approved, May 1999

Ruth A. Beck

Daniel A. Cristol

S. Laurie Sanderson

DEDICATION

To my grandparents, Joseph Durczak, Jeannette M. Durczak, and Grace Meyers; my parents, Alan Gordon and Celine Gordon, and my sister Frances Gordon for their strength and help throughout all times. Without their support, understanding, and simple willingness to listen, I would not have found guidance to continue. I am indebted to them for their kindness and generosity.

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ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge the Black Skimmer. Truly an elegant, magnificent bird whose presence instilled awe and wonder in a naïve student.

No project of this scale could ever have been accomplished without the extensive help and aid of numerous people. I am grateful to my thesis advisor, Ruth A. Beck, for coming up to a bewildered first year graduate student and suggesting a project which has altered my view of the world. She provided funding throughout the entire the project and offered support in terms of personnel, materials, and advice. Her professional relationships with the state and federal agencies made this project possible.

I am particularly grateful to the members of my committee, Daniel Cristol and S. Laurie Sanderson, for guiding me when I needed it most. Dr. Cristol taught me to think like a scientist and always kept raising the bar just a little higher. Even when I thought I couldn't make it, he kept pushing and believing in me. His suggestions for experimental design and analysis were critical and necessary for the completion of this project. For his honesty, integrity, and professional guidance, I will always be grateful. Dr. Sanderson believed in me from the start, without her help and understanding of fish biology, I would never have been able to complete this project. For taking time to lend an ear, suggesting the summer trawl surveys, and her help in reviewing the manuscript, she has been immeasurably helpful.

The Virginia Department of Transportation at the Hampton Roads Bridge Tunnel (HRBT) created a sanctuary at the junction of a major interstate, the port opening for the Atlantic Fleet Command and Norfolk Shipyards, and I-64 bridge construction. Their closure of the east bound I-64 South Island right-hand exit road enabled thousands of

shorebirds to nest undisturbed during the summer. Without the access granted to the vent tunnel roof, observations of skimmer breeding behavior would have been nearly impossible. In addition, their willing donation of hundreds of parking barriers, erosion cloth, and hundreds of tons of sand to prepare the island for the arrival of the skimmer was necessary for the development of a conservation area. As a state agency, they have gone beyond reasonable expectations to accommodate the nesting of over 8,000 migratory birds each summer and deserve recognition for this effort. Many individuals were responsible for the conservation effort including Don West, Jim Harrison, Edna Whittemore, Marvin Perkins, Buck Owens, Glenn Cooper, John Chambers, and the staff and personnel of HRBT South Island facility.

The Virginia Department of Game and Inland Fisheries and U. S. Fish and Wildlife provided legal assistance and helped communicate the importance of protection and conservation at HRBT.

At the Center for Conservation Biology, Bryan Watts and Mitchell Byrd provided equipment, experimental design suggestions, and access to breeding bird survey information. Dr. Watts was a sounding board for ideas concerning skimmer decline and provided current information regarding the status of the species.

The Williamsburg Bird Club provided a grant during my first year of study and invited me to talk about the project with members. I appreciated the opportunity to inform others about the project and was grateful for all of the helpful thoughts, ideas, and questions which were offered.

Fellow graduate students provided the day to day living experience that made my time in Williamsburg all that it could possibly be. Matt Turnbull's knowledge of

computer innards (unparalleled), statistical finesse, and personal insights were essential to finding my way around the world of science and life after undergrad days. Mark Stoetzer's support, laughter, and humor made it all worth it. Leah McDonald, Eric Dunlavey, and Magill Weber volunteered their time near the end of the season collecting data. Sean Majoy's insistence at knowing when I was going to finish helped propel me to the end. Jenny Gamble's help during 35° F days spreading out sand was second to none.

However, during the past summer, the help of three people in particular made all of my observations possible. Jason Riddle, Kathy Stephens, and Leslie Burdett were undergraduate interns who volunteered their time and energy in every aspect of the project. From the beginning when they helped establish nest enclosures, made observations during the feeding rate study, and recorded data during weekly nest checks in the early morning hours; their energy, enthusiasm, and humor were irreplaceable and I am truly indebted to each one of them for all of their help.

The annual migration of the William and Mary Biology Club to the island to help prepare for the return of the skimmer was essential. Without their meticulous efforts and skill at weed pulling, sand spreading, and erecting erosion cloth, the island would never have been ready for the skimmers.

I would like to thank the faculty of the Department of Biology for all of their support, suggestions, and criticisms. By always pushing me further ahead, you allowed me to excel beyond my wildest expectations. I would like to particularly thank Paul Heideman, Joseph Scott, Martin Mathes, Kirt Moody, Donna Ware, Stewart Ware, Martha Case, Lawrence Wiseman, and Patty Zwollo.

Of course, identification of the fish collected at HRBT and use of their beach seine survey data made VIMS Fisheries Science Laboratory an invaluable resource. In particular, I am grateful to Herb Austin, Pat Geer, and Donald Seaver for giving me the opportunity to experience the high seas firsthand (including the day I became seasick). I appreciate their willingness to share and donate information freely, their generosity and aid will be remembered.

Finally, the staff at William and Mary were there to provide comic relief and support (in the form of random emails, walks around campus to relieve stress). For all their efforts, I am grateful to Bill Saunders, Lydia Whitaker, Renee Peace, and Carlton Adams.

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ABSTRACT

In 1997 and 1998, breeding behavior of the Black Skimmer was studied on an artificial island virtually free of predators and storm effects in order to determine factors affecting reproductive success. No previous studies have investigated the quantitative relationship between hatching date, feeding rate and reproductive success in the Black Skimmer. Relative to several natural colonies, reproductive success was low at this colony on an artificial island. In spite of the virtual absence of predators, mortality was higher during the prefledging period than during the incubation period. Food delivery rates were low compared to a nearby colony on a natural island and one other natural colony. Parents which fed young more food fledged a greater proportion of nestlings. Food availability likely determines survival as first hatched young were more likely to fledge than others.

REPRODUCTIVE SUCCESS OF BLACK SKIMMERS

ON AN ARTICIAL ISLAND:

EFFECTS OF HATCHING DATE AND FEEDING RATE

INTRODUCTION

Since the early 1800's the number of black skimmer (*Rynchops niger*) colonies has dropped precipitously (Burger and Gochfeld 1990). Multiple pressures, including human development and habitat degradation, have forced colonial waterbirds to abandon traditional nesting sites, exposing them to new threats. These threats include predictable phenomena like increased human disturbance and predation, as well as unpredictable threats such as flooding and storms (Burger and Gochfeld 1990, Mathews 1995). On the eastern shore of Virginia, black skimmer numbers have declined precipitously from >10,000 adults in 1977 to <2000 in 1998 (Williams et al. 1998).

Several studies have attempted to measure the success of black skimmer colonies by measuring reproductive success (Table 1a, b). Black skimmers have been reported to suffer low reproductive success due to starvation, predation, human disturbance, rainstorms, and flooding (Smith 1982, O'Connell 1992, Keller 1992, Mathews 1995). The objective of this study was to determine factors affecting reproductive success on an artificial island virtually free from predators and storm effects.

If their preferred sandy beach or marsh habitat is not available, skimmers sometimes use alternative sites for breeding (Smith 1982, Mathews 1995). Alternative sites include artificially created habitats such as rooftops, dredge deposits, and man-made islands (Fisk 1978, Blus and Stafford 1980, Mathews 1995). The Hampton Roads Bridge-Tunnel (HRBT) spanning the Hampton Roads Harbor in Hampton, Virginia serves as such an artificial site. HRBT is attractive for skimmer nesting as it presents characteristics favorable for breeding, including: (1) an elevated island which minimizes

Table 1a. Black skimmer reproductive success from East and Gulf Coast populations

Location	Sample Size	Mean clutch size ± S.D. when available	Hatch Success (proportion)	Fledge Success (proportion)	# Chicks per nest	Reference
Barnegat Bay, NJ	133± 221	--	--	--	0.75	Burger and Gochfeld, 1990
Long Island, NY	190	3.70± 0.85	0.88	--	--	Safina and Burger, 1983
Cape Island, SC	57	3.8	0.35	0.95	1.2	Blus and Stafford, 1980
Laguna Vista, TX	94	3.44± 0.756	0.63	0.53	0.87	Custer and Mitchell, 1987
Lacava Bay, TX	105	3.3	0.60	0.46	0.67	King, Custer, and Quinn, 1991
Galveston Bay, TX	345	3.14	0.57	0.54	1.30	King and Krynitsky, 1986
South Texas Coast, TX	477	3.3	0.45	--	1.0	White et al., 1984
Laguna Madre, TX	353	3.18± 0.96	0.56	0.34	0.62	Depue, 1974
Fisher-Man's Island, VA	110	3.55	0.79	0.11	0.38	Erwin, 1977
Eastern Shore, VA-MD	118	3.13	0.53	0.39	0.58	Smith, 1982
Eastern Shore, VA	180	3.04	--	--	0.13	O'Connell, 1992

Table 1b. Black skimmer reproductive success from Hampton Roads Bridge Tunnel, VA

Location	**Sample size**	**Mean clutch size ± S.D. when available**	**Hatch Success (proportion)**	**Fledge Success (proportion)**	**# Chicks fledged per nest**	**Reference:**
HRBT, VA	27	3.00	0.17	--	--	Keller, 1992
HRBT, VA	31	2.10	0.21	--	--	Keller, 1992
HRBT, VA	350	2.44	0.23	0.15	0.09	Mathews, 1995
HRBT, VA	261	2.88	0.46	0.30	0.39	Mathews, 1995
HRBT, VA	300	2.99± .931	0.36	0.33	0.35	Gordon, 1997
HRBT, VA	251	2.75± .761	0.70	0.29	0.55	Gordon, 1998

the threat of flooding or washout from storms, (2) the absence of mammalian nest predators, (3) sandy substrate favorable for nesting, (4) adequate grass cover for use by hatchlings as refugia, and (5) negligible human intrusion.

At HRBT, where predation is virtually non-existent, observable disease and parasite problems are minimal, and breeding grounds are protected by breakwater, starvation due to declining food resources and parental ability to forage efficiently and effectively emerge as the likely candidates for determining fledging success. Skimmers carry only one fish back to the nest per foraging trip (pers. observation), so only by increasing the frequency of foraging trips can an adult increase food delivery rates to young. If the distance to foraging grounds is far, or fish are scarce, then adults may not be able to adequately provision young. Many studies have cited starvation as a primary cause of nestling mortality in black skimmers (Burger and Gochfeld 1990, Taylor 1997). Starvation as a function of hatch order (i.e. inability of younger nestlings to compete with older, larger siblings for food resources) has been implicated in limiting black skimmer fledging success (Erwin 1977, Depue 1974). No published studies of skimmer populations to date have examined quantitatively the relationship between food availability and reproductive success.

THE STUDY SITE

The Hampton Roads Bridge-Tunnel was opened in 1972 to connect Virginia's lower peninsula with the south side of Hampton-Roads (Figure 1a,b). It spans the opening of the James River, a tributary of Chesapeake Bay. The Bridge-Tunnel system is part of the east-west interstate highway (I-64) and serves as a transit corridor for an average of 100,000 cars per day. The skimmer colony is located on the south island (Lat. 36° 55'N, Long. 76° 30'W) anchoring the southern-most portion of the tunnel to a bridge connecting with the south side (Figure 1a). The south island itself is 460m long and 215m wide, although the colony utilizes only the western-most portion of the island. The Virginia Department of Transportation (VDOT) station on the south island operates 24 hours a day during the year as a maintenance and emergency facility assisting disabled vehicles.

The island has been monitored for colonially nesting waterbirds since 1980 (Beck pers. comm.) and it is managed each year in preparation for the nesting of migratory shorebirds. The colony is located on the western-most portion of the island. This area is isolated from vehicular traffic and human intrusion from April 1 to September 15 in order to reduce detrimental effects associated with disturbance (Safina and Burger, 1983). In cooperation with VDOT personnel, Hampton-Roads Sheriff's Trustees, and the William and Mary Biology Club, tracts are established with bulldozed sand in to provide nesting substrate favorable for skimmer hatching success (see methods, Mathews, 1995). The vegetation of the island is dominated primarily by grasses during the summer. Before and after the breeding season, the island is mowed to control growth of vegetation.

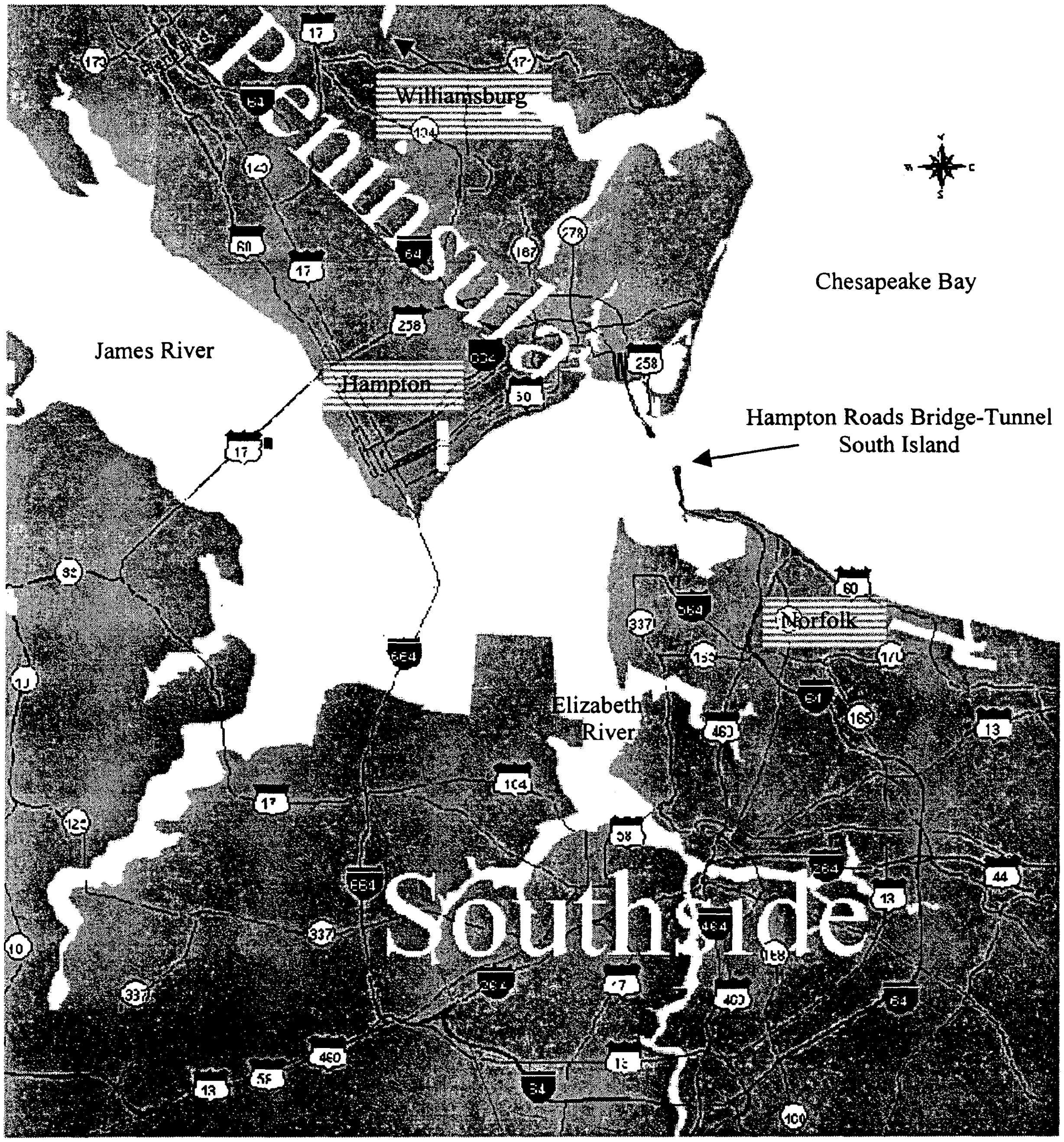


Figure 1a. Map of Southeastern Virginia illustrating location of Hampton Roads Bridge-Tunnel spanning the opening of the James River

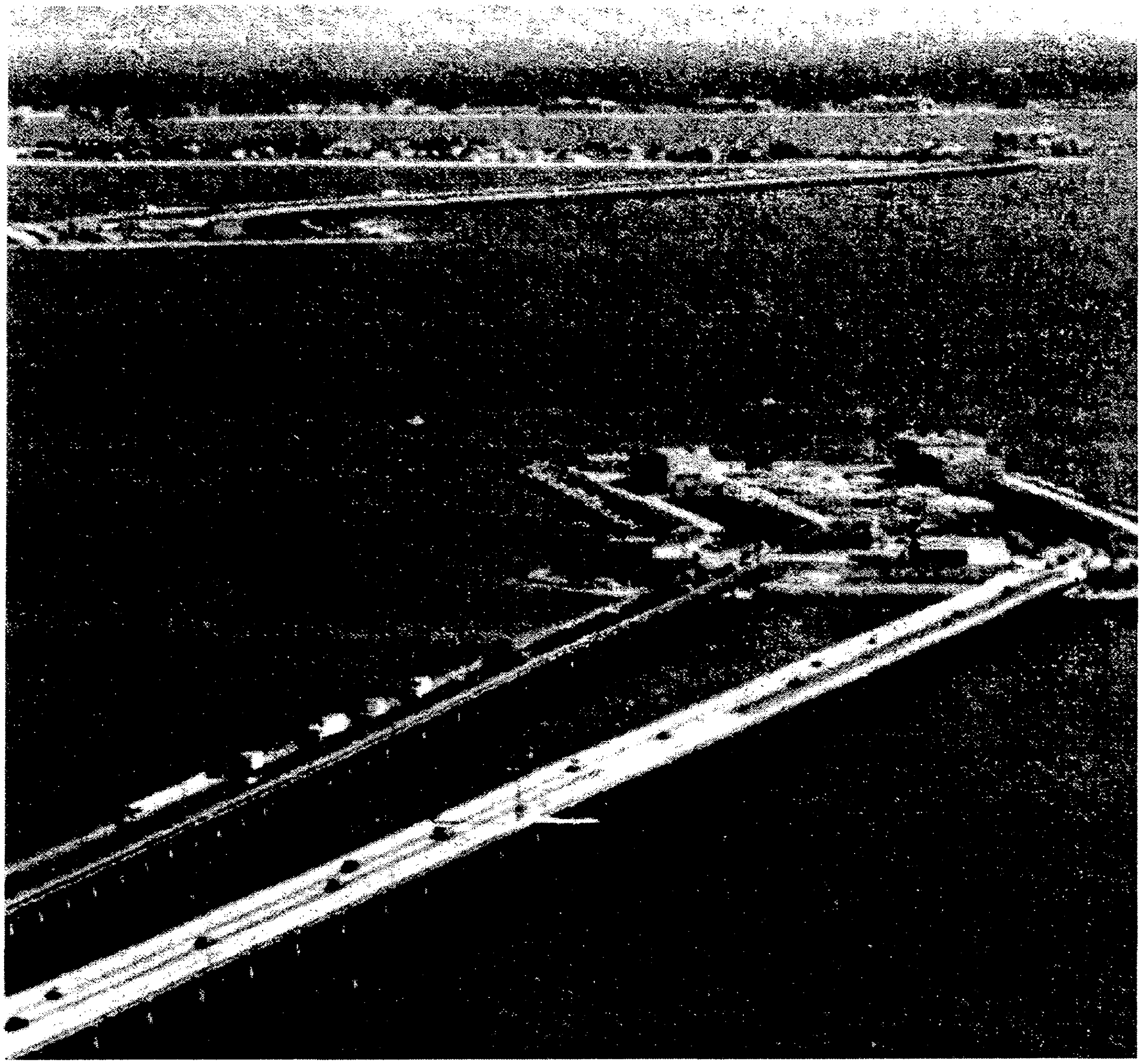


Figure 1b. Aerial view of Hampton Roads Bridge-Tunnel showing the study site

METHODS AND MATERIALS

Monitoring Reproductive Success

From 1 April to 15 September 1998 black skimmer nests, eggs, hatchlings, and fledglings were monitored at HRBT to determine reproductive success. Thirteen plots (five 10m x 10m, eight 30m x 2m) with bulldozed sand substrate were established for skimmer nesting in early February (Figure 2, Mathews 1995). Poly-coated vinyl mesh poultry wire (2.54cm gauge, approximately 30cm high) was used to enclose ten of the thirteen randomly selected plots in order to allow determination of the fate of fledged young by constraining their movement (Erwin 1977, Smith 1982). The fate of nest contents in the plots was followed through the breeding season using a combination of daily rooftop observations and visits to approximately half the colony every third day. Nests were marked with numbered white utility survey flags. When young hatched, down feathers on the lower back were individually marked with a maximum of four dots or dashes using acrylic nail polish. Young were considered fledged if they survived to 21 days of age, which coincides with the ability to fly and escape the enclosures (Burger and Gochfeld 1990).

Monitoring Feeding Rate

The feeding of young by adults was monitored from 23 June until 1 August 1998 using a combination of day and night observations. Daytime observations were made on 21 days between 23 June and 13 July (101.25 hours). During daylight observations, seven plots containing a total of 62 nests were monitored. Each plot (n=9 nests minimum) was monitored for one hour each day (between 0530 and 2030), blocked for tide and time of day. Each nest was monitored for a total of 7-14 hrs over the course

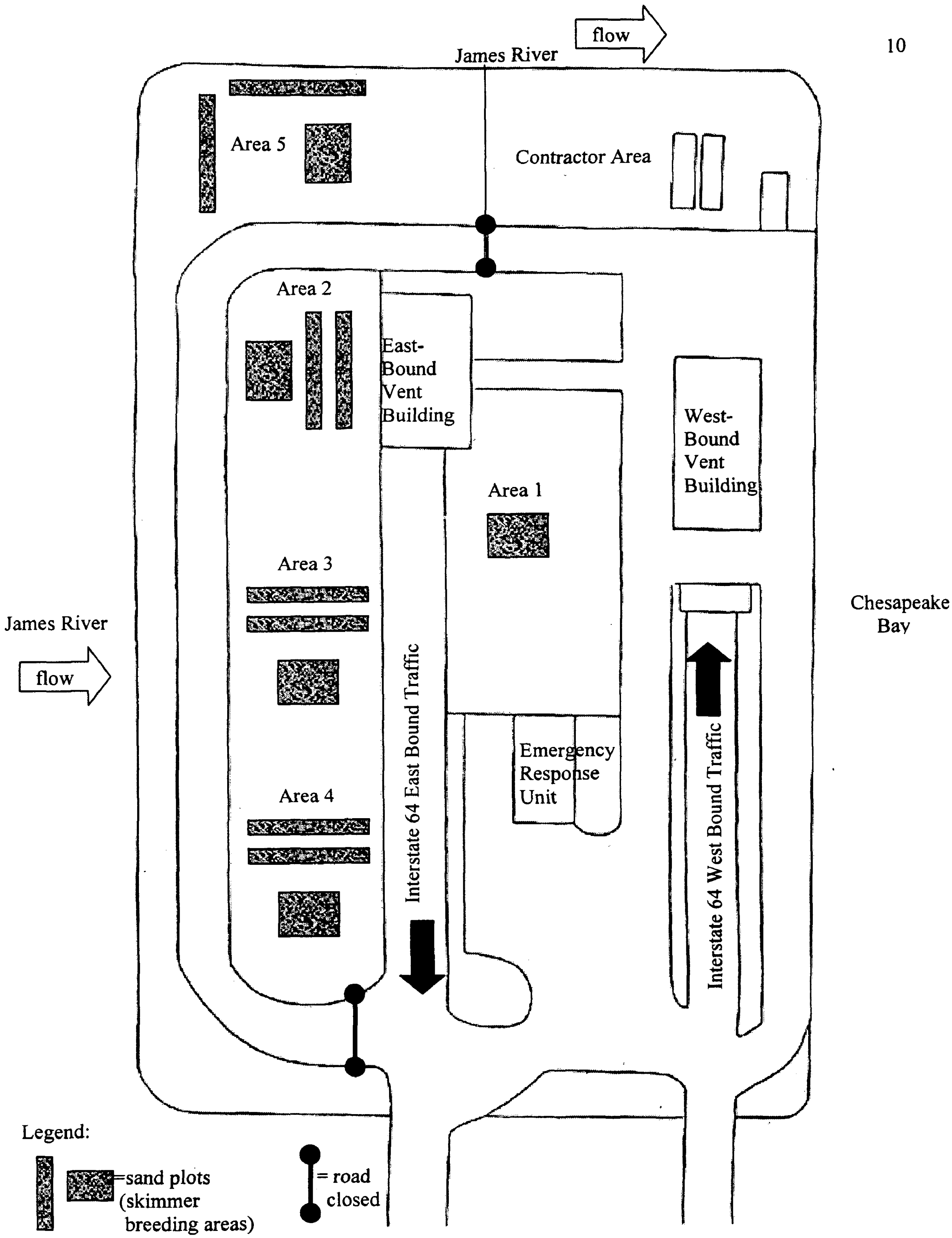


Figure 2. Diagram of Hampton Roads Bridge-Tunnel South Island illustrating location of skimmer breeding areas

21 days. Night observations were made on 7 days between 15 and 21 July (36 hours). These observations included only one subplot (Area 1, Fig. 2) which was observed continuously from 2100-0300, under dim, artificial light for 36 hours of observation on 25 nests. Both day and nighttime feeding rates were sampled at 14 of these nests. Each of these 14 nests was observed for a total of 47-49 hours during the day and night. All feeding rate observations were made from a rooftop overlooking the colony using 10x binoculars and a 15x spotting telescope. During daylight observations, time, nest number, sex of adult, size of prey, size of young, and outcome of feeding (i.e. prey eaten by young or adult, dropped, stolen) were recorded for each food delivery. During night observations, only time, nest number, size of prey, and size of young could be recorded due to limited light.

Monitoring Growth

Young (n=126) in 59 randomly selected nests were measured using four characters as indicators of growth; (1) weight; (2) culmen length; (3) wing cord; and (4) tarsometatarsus length. Weight was measured to the nearest gram using a Pesola spring scale. Length was measured to the nearest 0.01 mm using a dial caliper. To reduce human disturbance, approximately half of the selected nests (n=30) were measured alternately during nest checks on every third day from 27 June until 12 August (i.e. growth measurements on a particular nest were made at six day intervals).

Analyzing Reproductive Success

Reproductive success was analyzed using a combination of parametric and non-parametric statistical tests as noted. Linear regression was used to analyze time-dependent events unless otherwise stated. The Mayfield Method, an estimator of nest success based on days of nest observation, was used to analyze the probability of survival and mortality during the incubation and pre-fledging phases in the breeding cycle (Mayfield 1960, 1975). Chi-square tests were used to compare probability of survival and mortality between incubation and pre-fledging phases. HRBT and other breeding sites were compared using a Mann-Whitney U test.

Analyzing Feeding Rate and Reproductive Success

Linear regression analysis was used to determine whether daytime feeding rates explained variation in the number and proportion of fledglings produced per clutch, and to determine whether night time feeding rates explained variation in fledging success. All feeding rates were corrected for the number of hatchlings per nest. Those nests where feeding rates were sampled during both day and night observation times were used to determine if daytime feeding rates were related to night time feeding rate. Day and night time feeding rate observations were averaged to determine whether feeding rate explained variation in fledging success (# young fledged per nest and proportion young fledged per nest).

Analyzing Growth Patterns

Logistic equations were fitted to growth curves in order to quantitatively describe the growth patterns observed (Ricklefs 1967, 1968). Linear regression was used to determine the line of best fit among logistic, Gompertz, and von Bertalanffy growth equations (Ricklefs 1967). The growth constant, K, was calculated from the slope of the logistic regression line in order to compare growth rates between males and females at this site and other published data (Erwin 1977, Burger and Gochfeld 1990).

Survival and Time until Death of Young

In nests where individual young were identified the total number of days that each young lived was recorded. The mean number of days that first, second, and third hatched young lived were compared using a one-way ANOVA. Post-hoc multiple comparisons were performed using the test of least-significant differences. Linear regression was also used to determine the strength of the relationship between hatch order and the total number of days nestlings lived. Logistic regression was used to determine whether hatch order explained variance observed in fledging success.

Analyzing Seine Survey Data

Fish abundance data was obtained from two surveys conducted by the Virginia Institute of Marine Science in 1998 (Bluefish seine survey and Juvenile Striped Bass seine survey: see methods in Austin et al. 1998). Fish abundance was plotted against time using linear and quadratic regression to examine seasonal trends in availability of the two most utilized prey species. Long-terms trends in Atlantic needlefish (*Strongylura marina*) and menhaden (*Brevoortia tyrannus*) abundance were obtained from the Juvenile Striped Bass Seine Survey conducted by VIMS and the Maryland Division of Natural Resources. Atlantic needlefish and menhaden abundance were plotted against time using linear regression to examine long-term fluctuations in population levels.

Prey Availability

Dropped prey items were collected at HRBT every third day from approximately half the colony during nest checks. Whole and partial remains of prey items were bagged, dated and frozen within two hours of collection. All fish collected were identified to species level when possible (with the help of VIMS Fisheries Science Laboratory).

Length of prey items were measured to the nearest 0.1 mm, weight was recorded to the nearest 0.01 grams. When partial remains were collected, the equation from a linear regression of whole fish was used to estimate total length (Appendix A; Wilson, 1995). Visually estimated size of prey items fed to small, medium, and large young at night and day were compared by t-tests, ANOVA's, or non-parametric Kruskal-Wallis tests where noted. Whole length to mass regressions from Atlantic needlefish and menhaden were used to estimate biomass.

Groundtruthing

It was necessary to determine the accuracy of fish total size estimates observed during day and nighttime feeding observations. Using 10x binoculars and a 15x spotting scope, visual estimates of total length were made on 25 fish. Linear regression of estimated size to predict actual size was used to determine accuracy of measurements. See results and Appendix C for actual methods and values obtained.

RESULTS

Reproductive Success: Egg, Hatching, and Fledging Success

Skimmers began arriving at HRBT on April 16, 1998 and the first nest was initiated on May 5, 1998. Skimmers nested with approximately 3000 pairs of common terns (*Sterna hirundo*) and 50 pairs of gull-billed terns (*Gelichelidon nilotica*). Clutch size, proportion of eggs hatching, and number of chicks fledged per nest were all significantly lower than the mean for all east and gulf coast colonies (Table 2). There was no damage to eggs or young from flooding, rainstorms, or tidal surge. Predation was almost nonexistent on eggs or young. Egg predation by migrating ruddy turnstones (*Arenaria interpres*) was observed for one week in late May, but accounted for only 9% of hatching failure.

Reproductive Success and Date

Mortality was significantly higher during the pre-fledging period than during the incubation period (see Table 3; X^2=112.81, df=1, p<0.05). Date of clutch initiation significantly affected nest success. The number of eggs laid per nest decreased through time (Figure 3; $r^2 = 0.111$, $F_{1,\ 250}$=31.14, p=0.0001). Date was also significantly correlated with the number (Figure 4; r^2=0.157, $F_{1,\ 250}$=46.54, p=0.0001), and the proportion (Figure 5; r^2=0.109, $F_{1,\ 250}$ =30.71, p=0.0001) of eggs which hatched per nest. Although the number of fledglings produced per nest decreased through time, the relationship was weak (Figure 6; r^2=0.032, $F_{1,\ 201}$ =7.77, p=0.006). The proportion of young fledged per nest was not related to date (Figure 7; r^2=0.001, $F_{1,\ 201}$ =0.237, p=0.627).

Table 2. Comparison of Black skimmer reproductive success at the Hampton Roads Bridge Tunnel with East and Gulf Coast sites.

Site	Mean clutch size	Hatch Success (proportion)	Fledge Success (proportion)	# Chicks per nest
HRBT	2.69$\pm$ 0.36 (weighted: 2.74)	0.36$\pm$ 0.20 (weighted: 0.41)	0.27$\pm$ 0.01 (weighted: 0.26)	0.35$\pm$ 0.19 (weighted: 0.32)
East and Gulf Coast sites	3.36$\pm$ 0.26 (weighted: 3.41)	0.60$\pm$ 0.16 (weighted: 0.58)	0.47$\pm$ 0.26 (weighted: 0.44)	0.75$\pm$ 0.36 (weighted: 0.81)
Mann-Whitney U-test	p=0.001	p=0.045	p=0.059	p=0.034

Table 3. Nest success, egg success, and estimated number of young leaving black skimmer nests

Colony	Number of nests	Nest Success[a] Incub. period	Pre-fledge period	Nest Success	Hatch Success	Chick Success	Egg Success	Mean clutch size	Estimated young leaving nest
		(A)	(B)	(AxB)	(C)[b]	(D)[c]	(AxBxCxD)	(E)	(AxBxCxDxE)
HRBT	252	0.87	0.43	0.37	0.78	0.54	0.16	2.92	0.47

a. The probability that at least one egg or young survived for a given period (hatch-21days, fledge-21days)
b. The probability of an egg hatching, given that the nest was successful
c. The probability of young living to 21 days given that the nest was successful

Figure 3. Relationship between clutch size and date

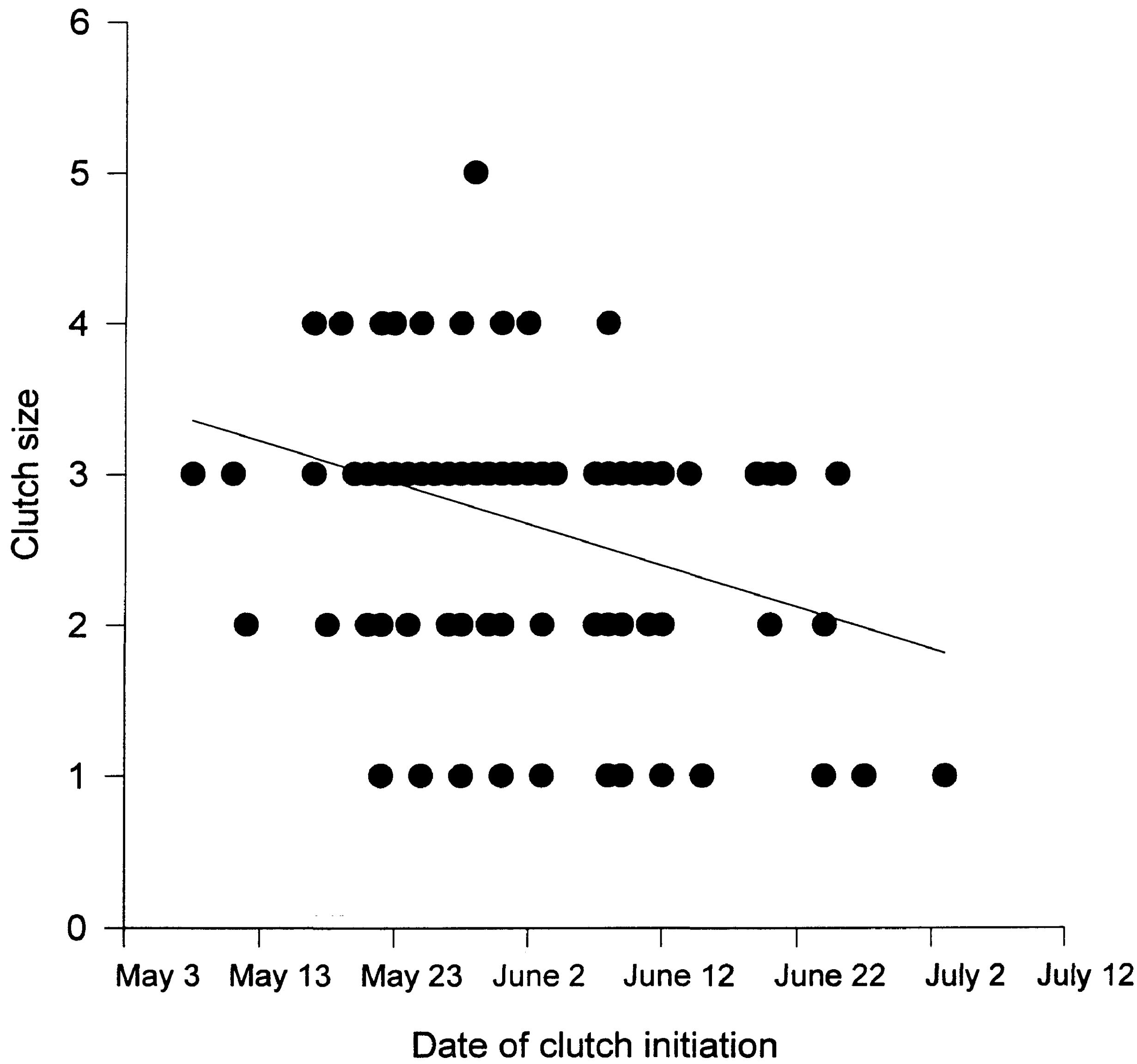


Figure 4. Relationship between number of young hatching per nest and date

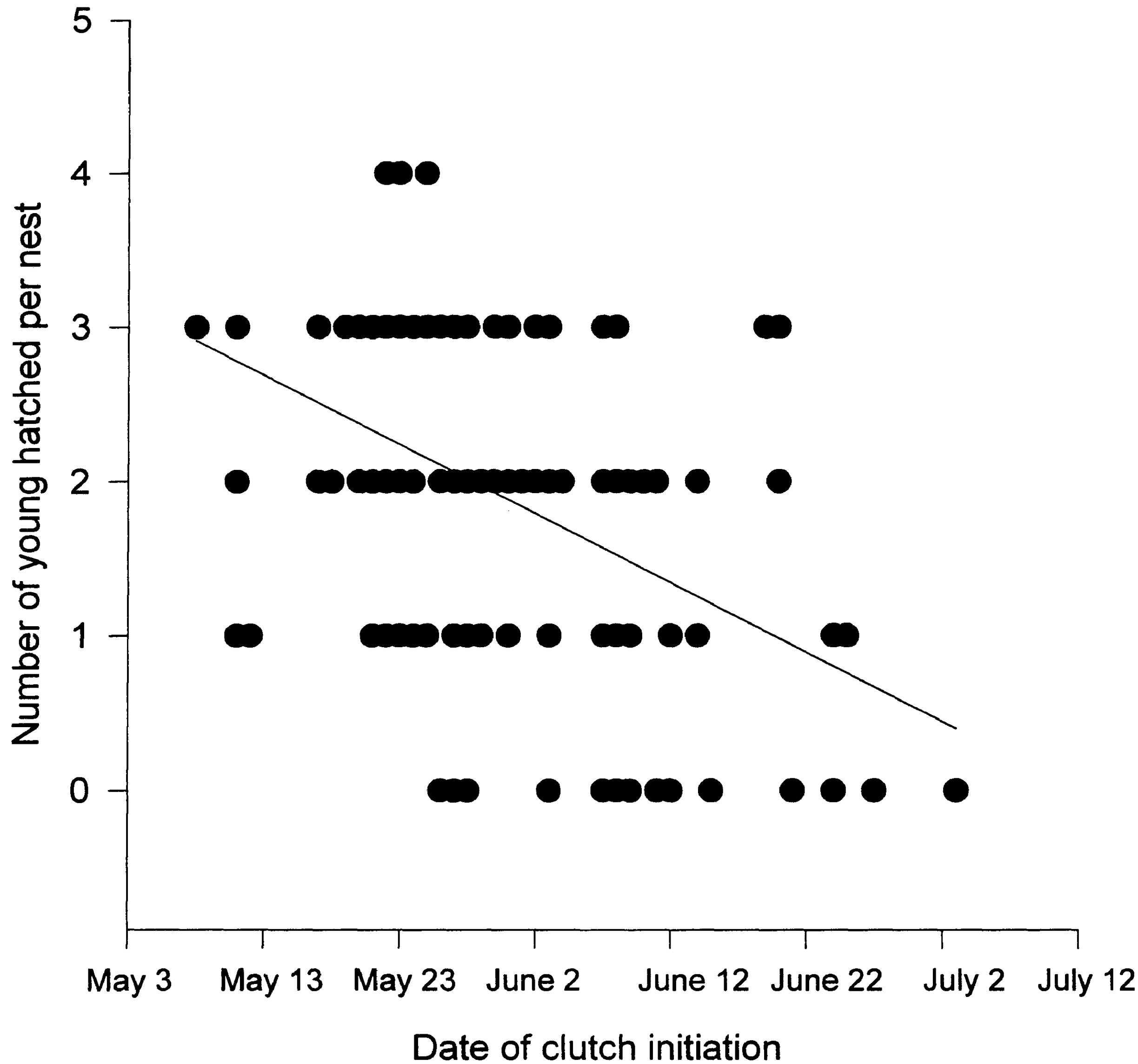


Figure 5. Relationship between proportion of young hatching and date

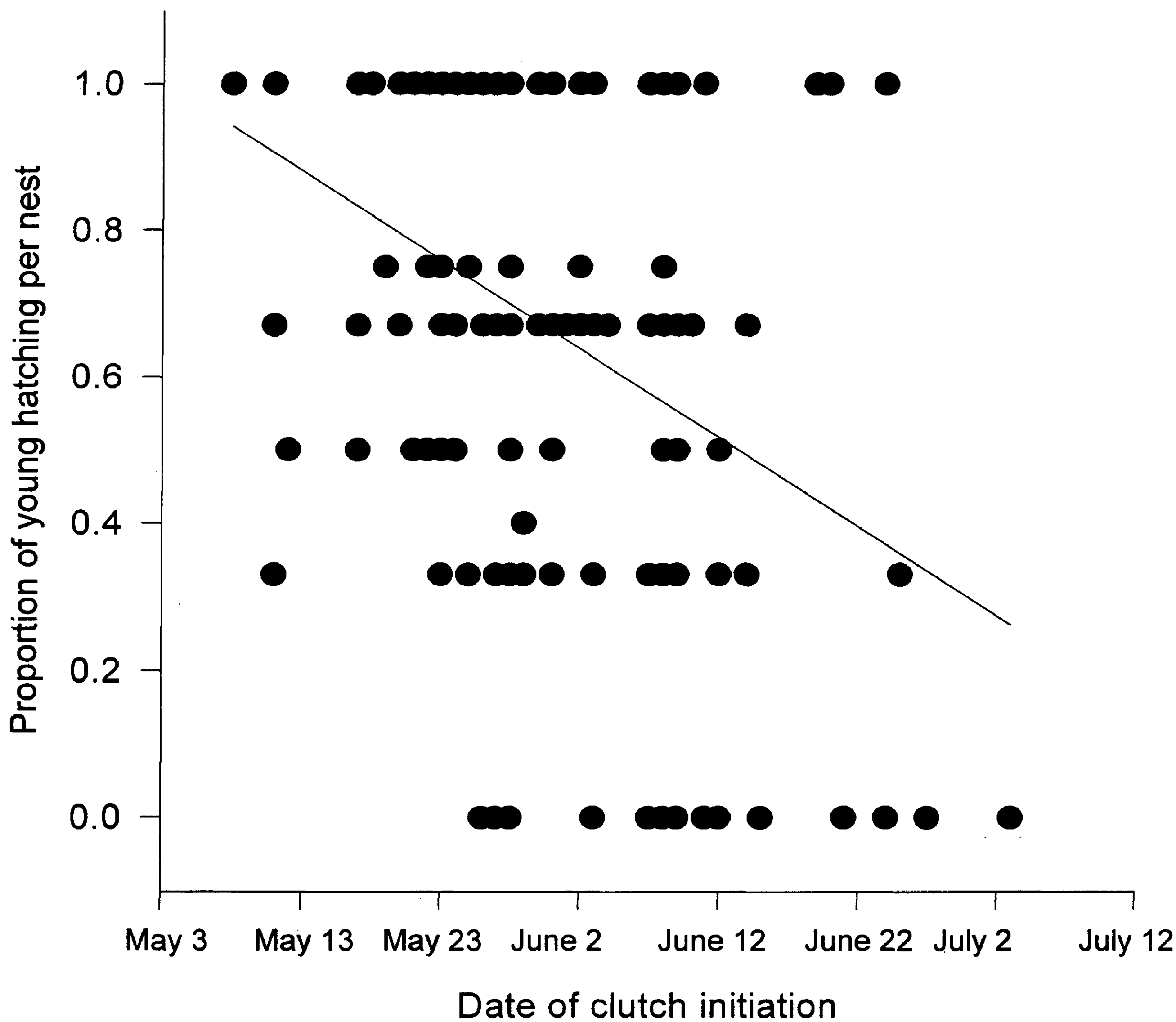


Figure 6. Relationship between number of young fledging and date

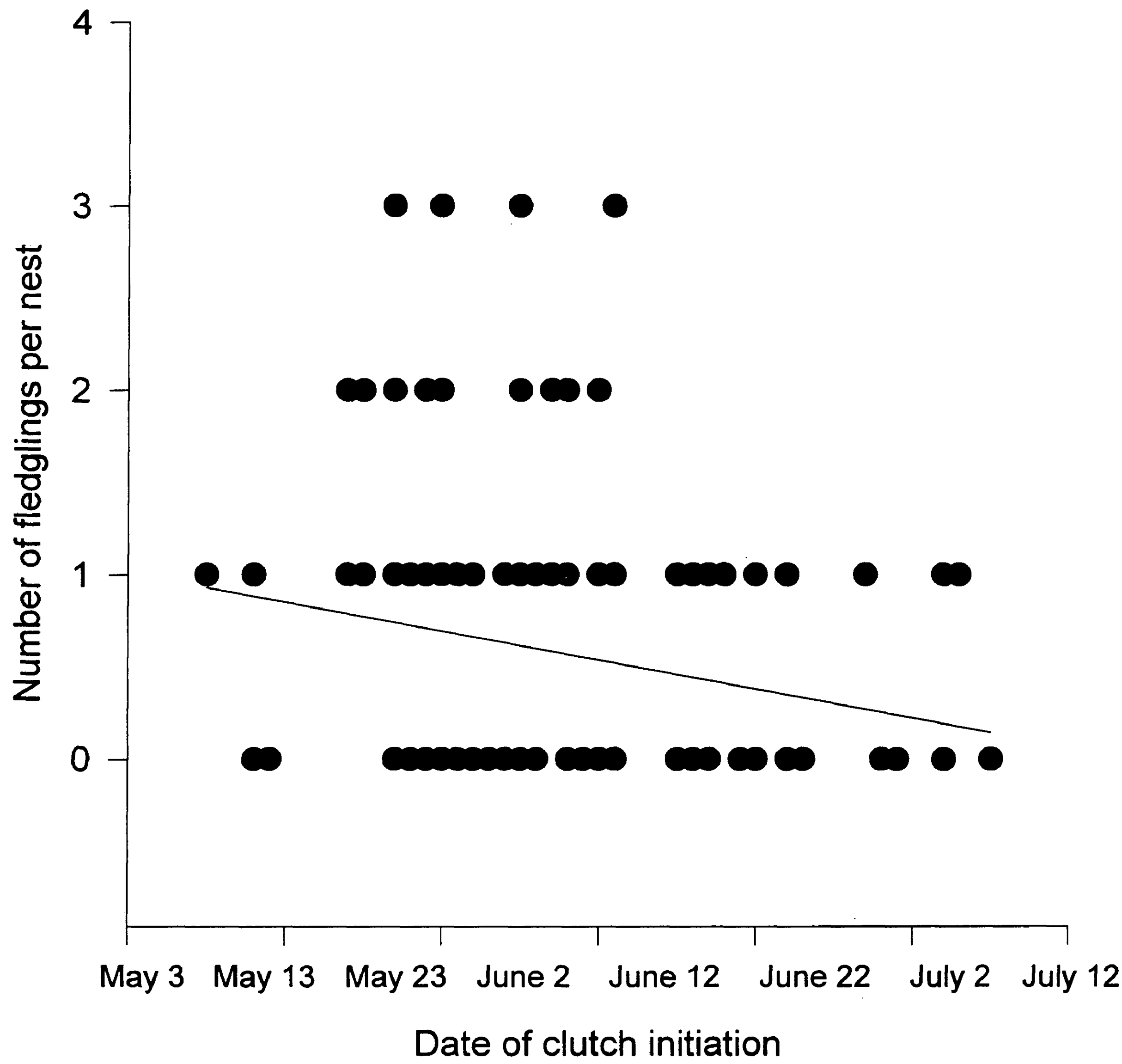
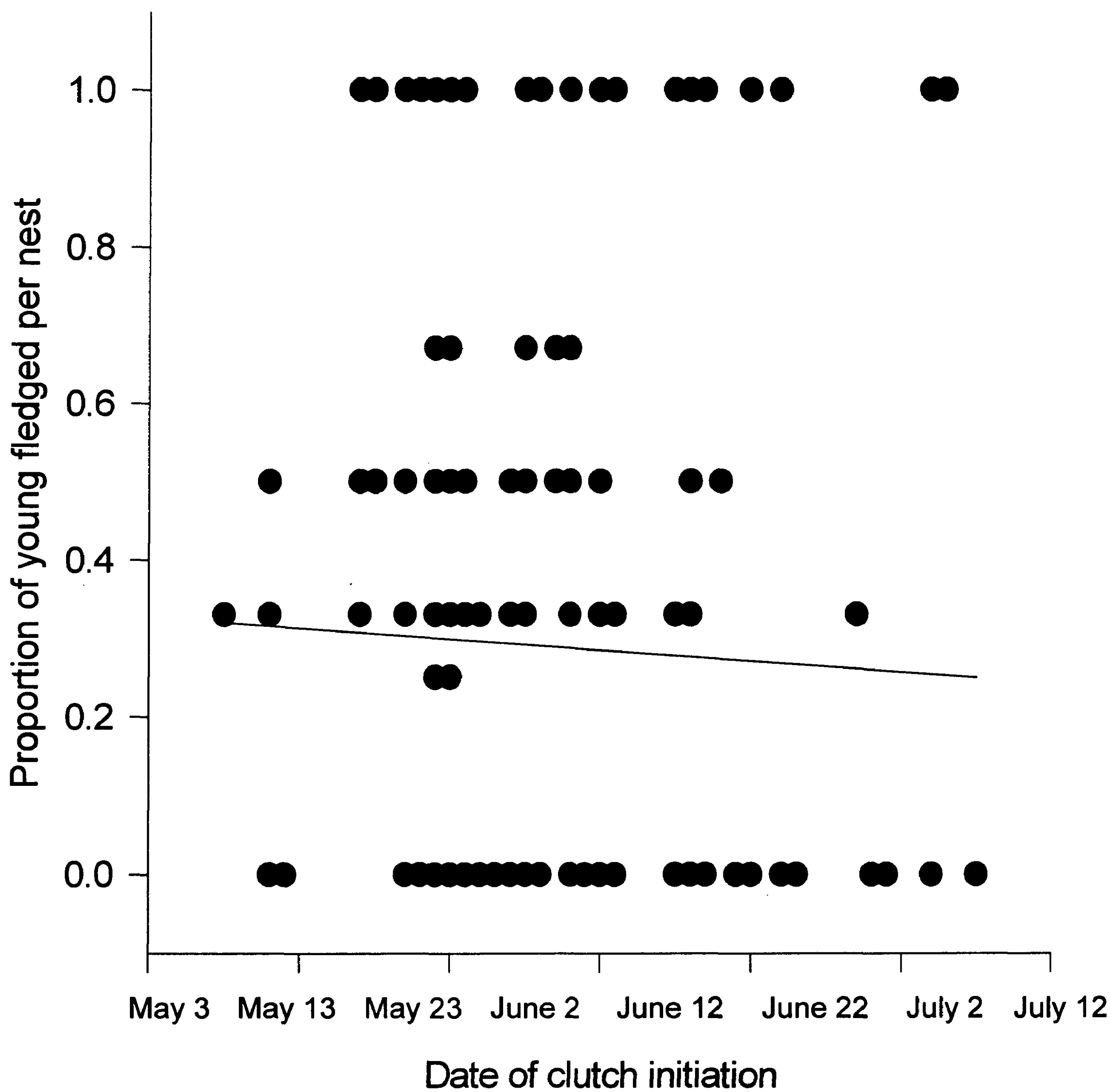


Figure 7. Relationship between proportion of young fledging and date



Mean Feeding Rate and Reproductive Success

Mean feeding rate at nests sampled during the day was 0.075 ± 0.06 fish/hour/nestling. Mean feeding rate at nests sampled at night was almost three times higher (0.21 ± 0.20 fish/hour/nestling). At the sub-sample of nests where day and night feeding rates were observed, the combined mean feeding rate was 0.18 ± 0.130 fish/hour/nestling. Parents that fed nestlings more at night were more likely to feed young during the day (Figure 8; n=14, $r^2=0.480$, $F_{1, 12}=11.09$, p=0.006).

Feeding Rate and Reproductive Success

Parents which fed chicks more at night were likely to fledge more young per nest (Figure 9; n=25 nests, $r^2=0.354$, $F_{1, 23}=12.62$, p=0.002). This was also true if the combined average of day and night rates was used (Figure 10; $r^2=0.359$, $F_{1, 12}=6.71$, p=0.024). Parents that fed nestlings more during the day also tended to fledge more young but the relationship is not significant (Figure 11; n=62 nests, $r^2=0.043$, $F_{1, 60}=2.70$, p=0.105).

Survival, Reproductive Success, and Date

Early hatched young survived longer, as hatch order was significantly related to survival ($r^2=0.447$, $F_{1, 124}=97.257$, p=0.0001). The mean number of days each nestling survived differed significantly between first- (n=59), second- (n=45), and third-hatched (n=22) young (Figure 12; $F_{2, 123}=49.687$, p=0.0001). Multiple comparisons between number of days survived and hatch order also indicated a significant difference between each first- and second-, second- and third-, and first- and third- hatched young (mean days survived based on hatch order: first=17.18; second=9.83; third=5.36; 1>2:p=0.0001; 2>3: p=0.001; 1>3: p=0.0001). Hatching date did not significantly affect days until death

Figure 8. Relationship between day and night feeding at individual nests

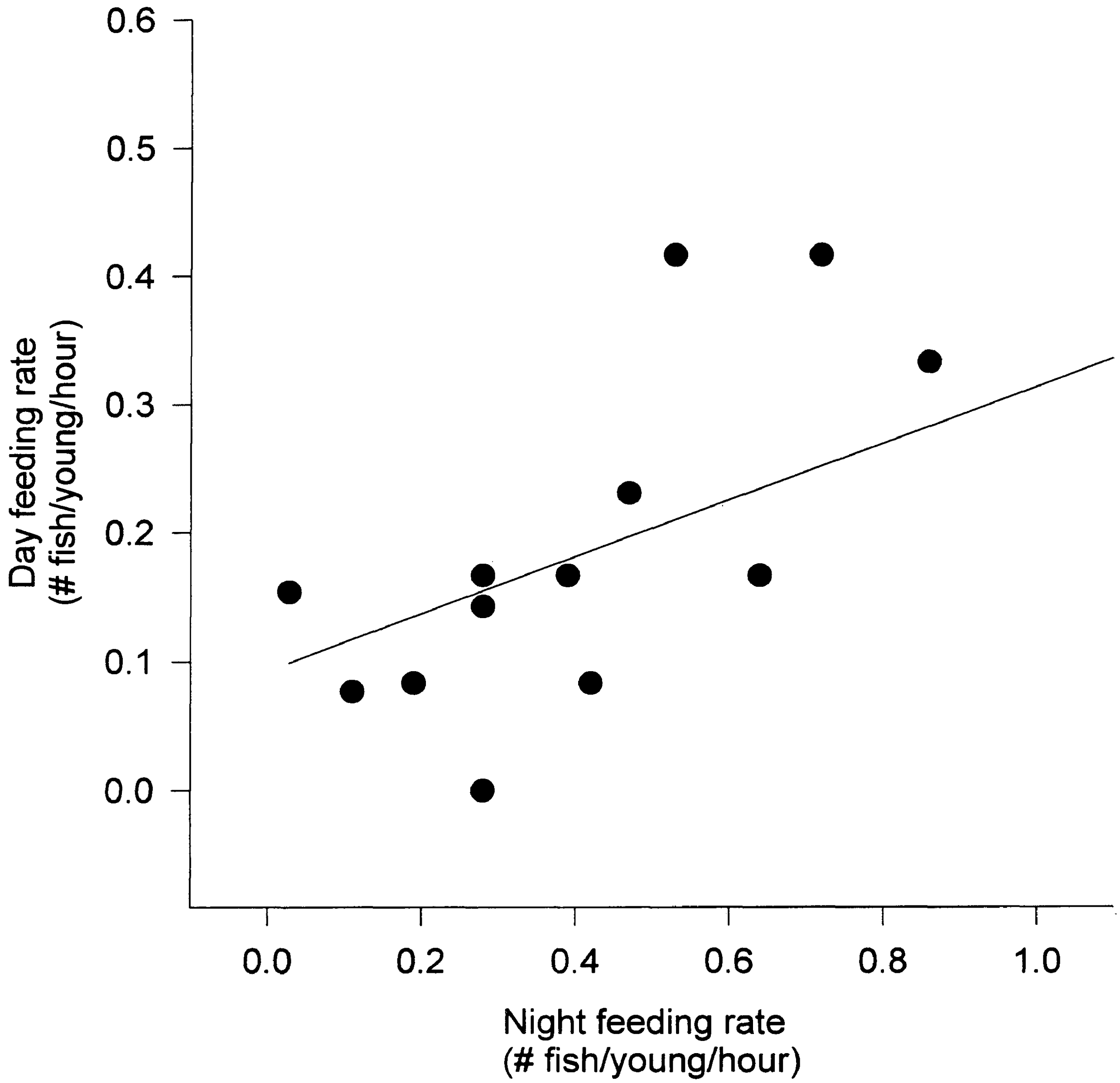


Figure 9. Relationship between night feeding rate and the proportion of young fledged per nest

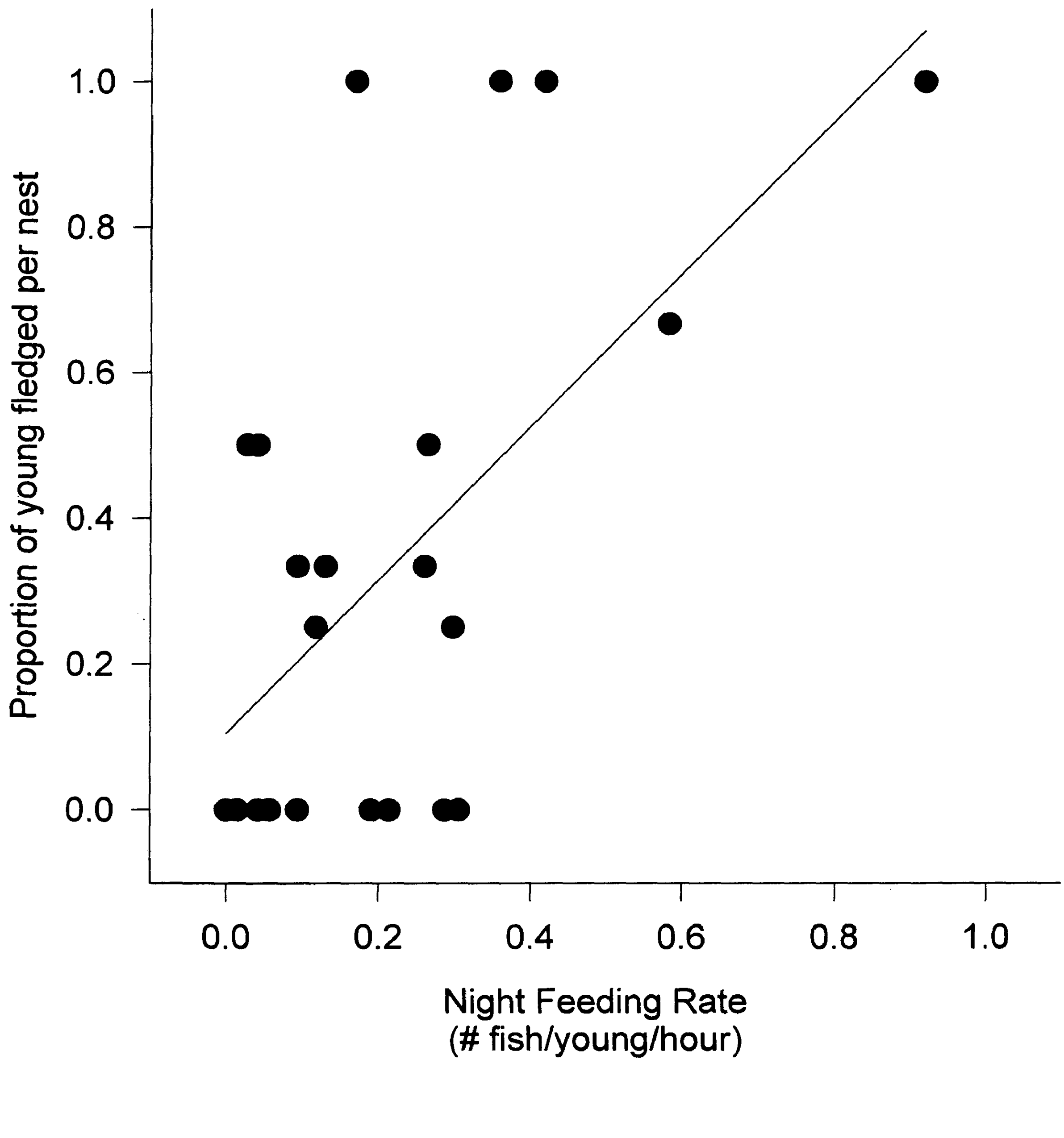


Figure 10. Relationship between combined feeding rates (day and night) and the proportion of young fledged per nest

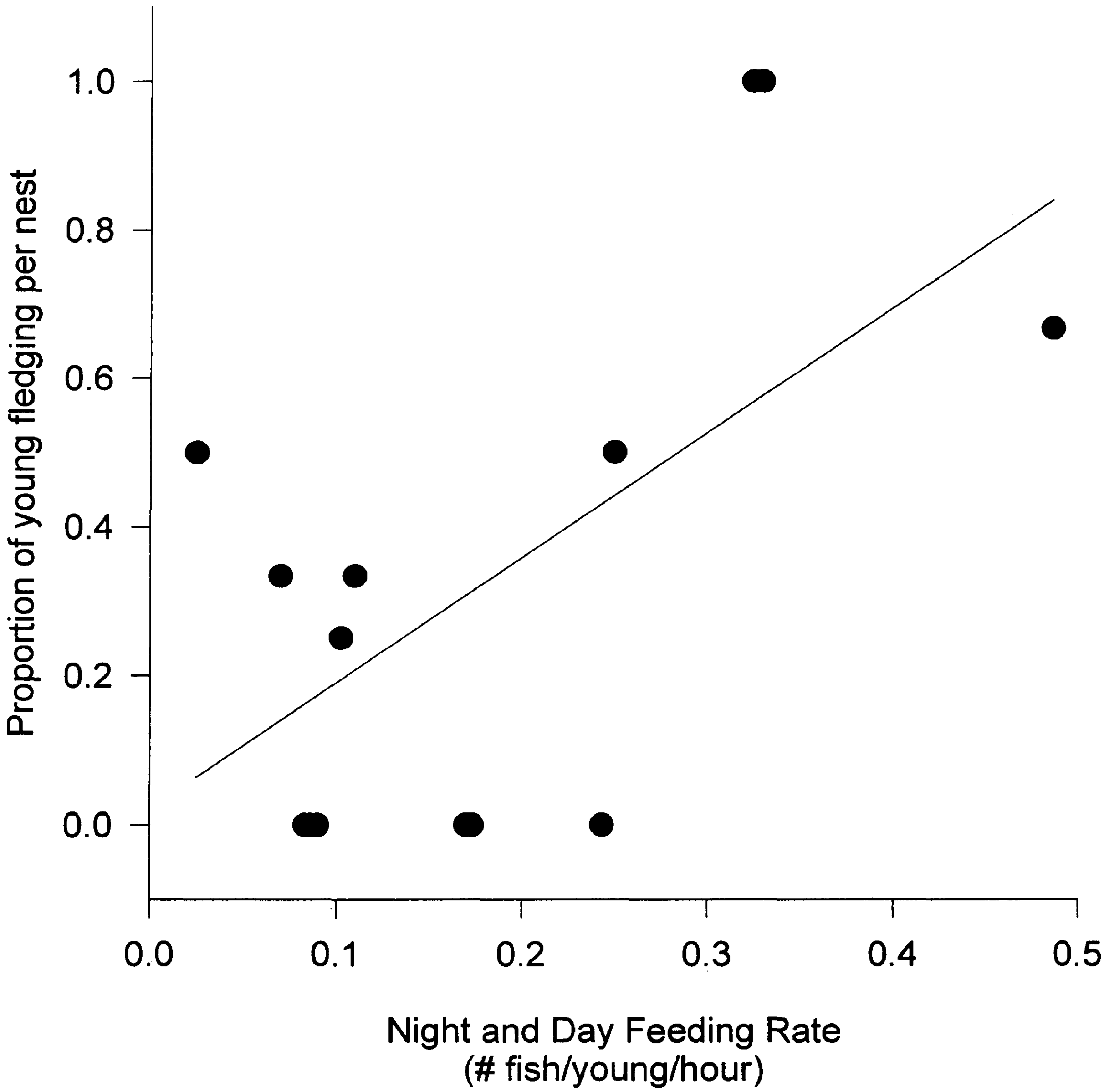


Figure 11. Relationship between day feeding rate and proportion of young fledged per nest

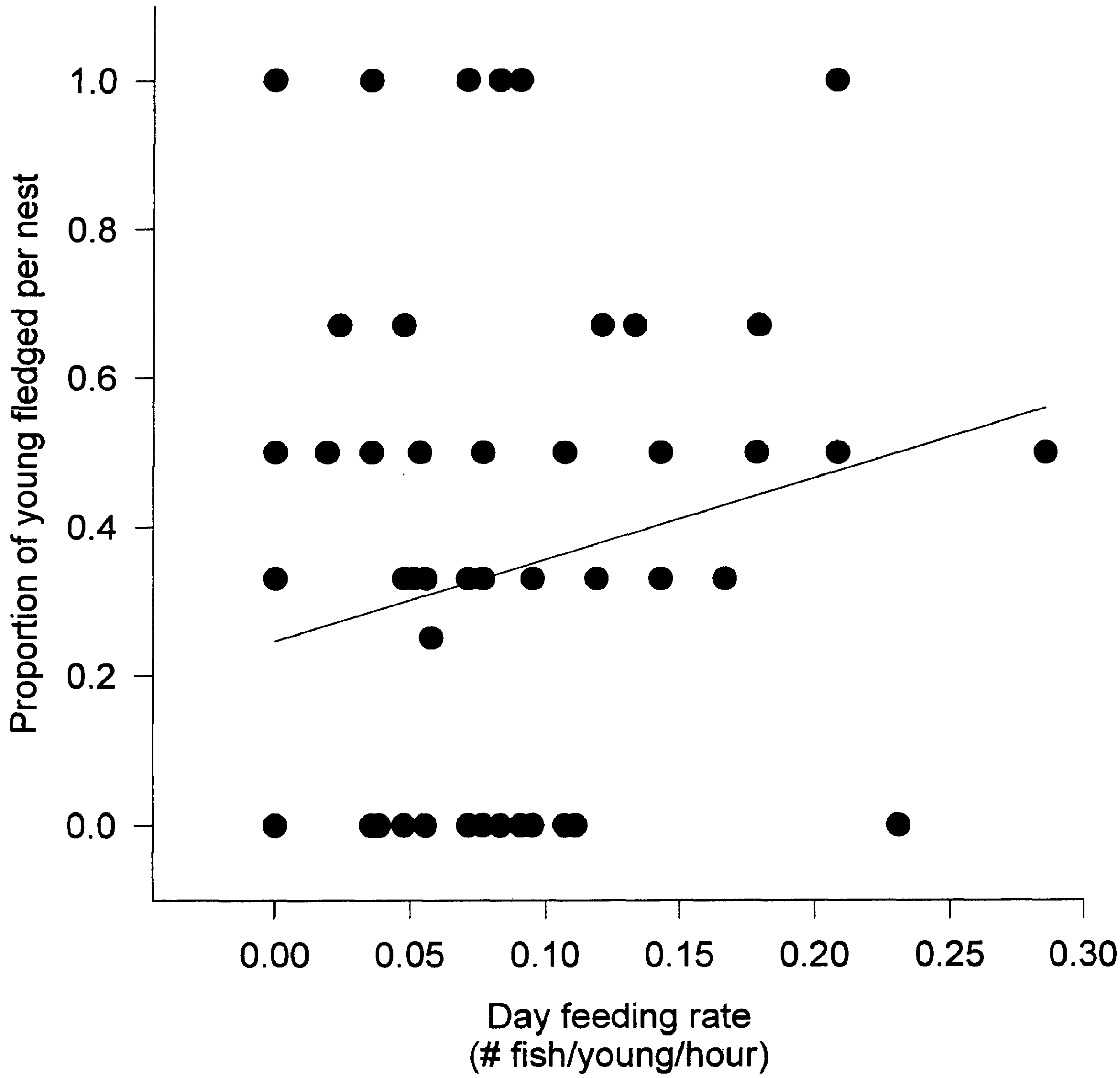
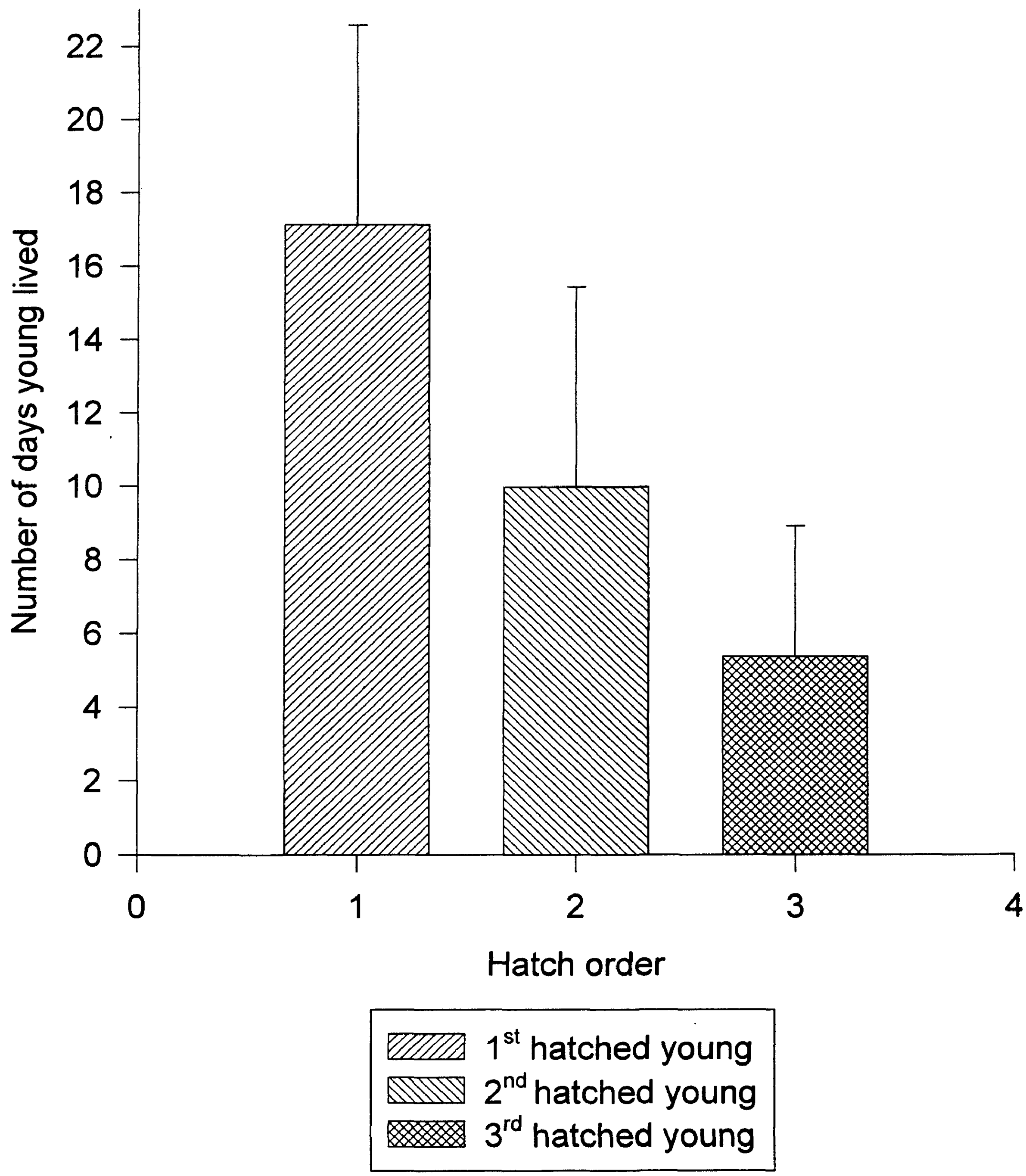


Figure 12. Comparison of chick lifespan between first-, second-, and third-hatched young



of young (r^2=0.001, $F_{1,124}$=0.140, p=0.740). Survival to fledging of hatched young was significantly affected by hatch order (Cox and Snell r^2=0.347, df=1, p=0.00001). Of thirty-seven successful nests, thirty-two fledged only the first-hatched chick.

Prey Availability

During the 1998 breeding season, 268 fish were collected from the skimmer colony at HRBT (Appendix C). Six different fish species represented approximately 90% of the fish collected in 1998 (Figure 13). Atlantic needlefish and menhaden alone accounted for 72% of total fish collected, so analyses were restricted to these two species. Both species are present seasonally and use shallow, shoreline nursery grounds. Seine surveys indicate that menhaden peak in late May, while needlefish peak in early July (Austin et al. 1998). Regression analyses of Atlantic needlefish and menhaden abundance indicate a significant decline during the breeding season (Figure 14, Atlantic needlefish: r^2= 0.485, $F_{2,9}$= 4.24, p=0.05; Figure 15, menhaden: r^2=0.511, $F_{2,9}$ =4.70, p=0.04).

Growth Rates of Young

Since skimmer young exhibit sexual dimorphism, growth rates of males and females were analyzed separately using logistic growth equations (Ricklefs, 1967). Male skimmers (n=10, mean weight $\pm$ S.D. = 305$\pm$27.79g) fledged at a significantly larger weight (t=6.651, df=20, p=0.0001) than females (n=12; mean weight $\pm$ S.D. = 243$\pm$15.08 g). The sex of young could be distinguished on the basis of weight after approximately fifteen days (Figure 16). The logistic growth equations used to plot weight gain through time met the parameters established by Ricklefs for the "line of best fit" when analyzed by linear regression (males: r^2=.925, $F_{1,10}$=122.72, p=0.0001; females: r^2=.907

Figure 13. Prey availability as determined by fish collections during summer 1998 at HRBT

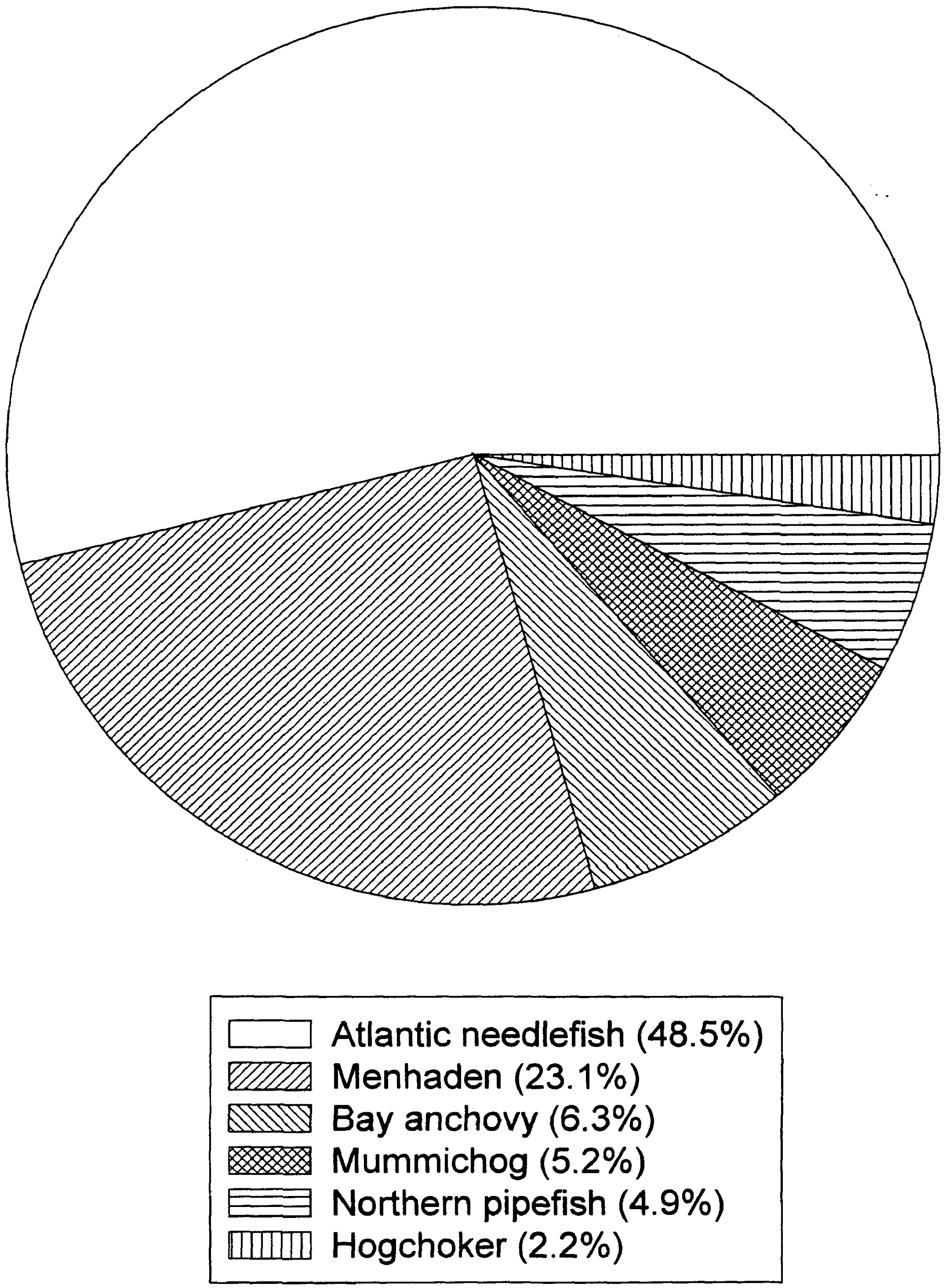


Figure 14. Atlantic needlefish abundance within a season

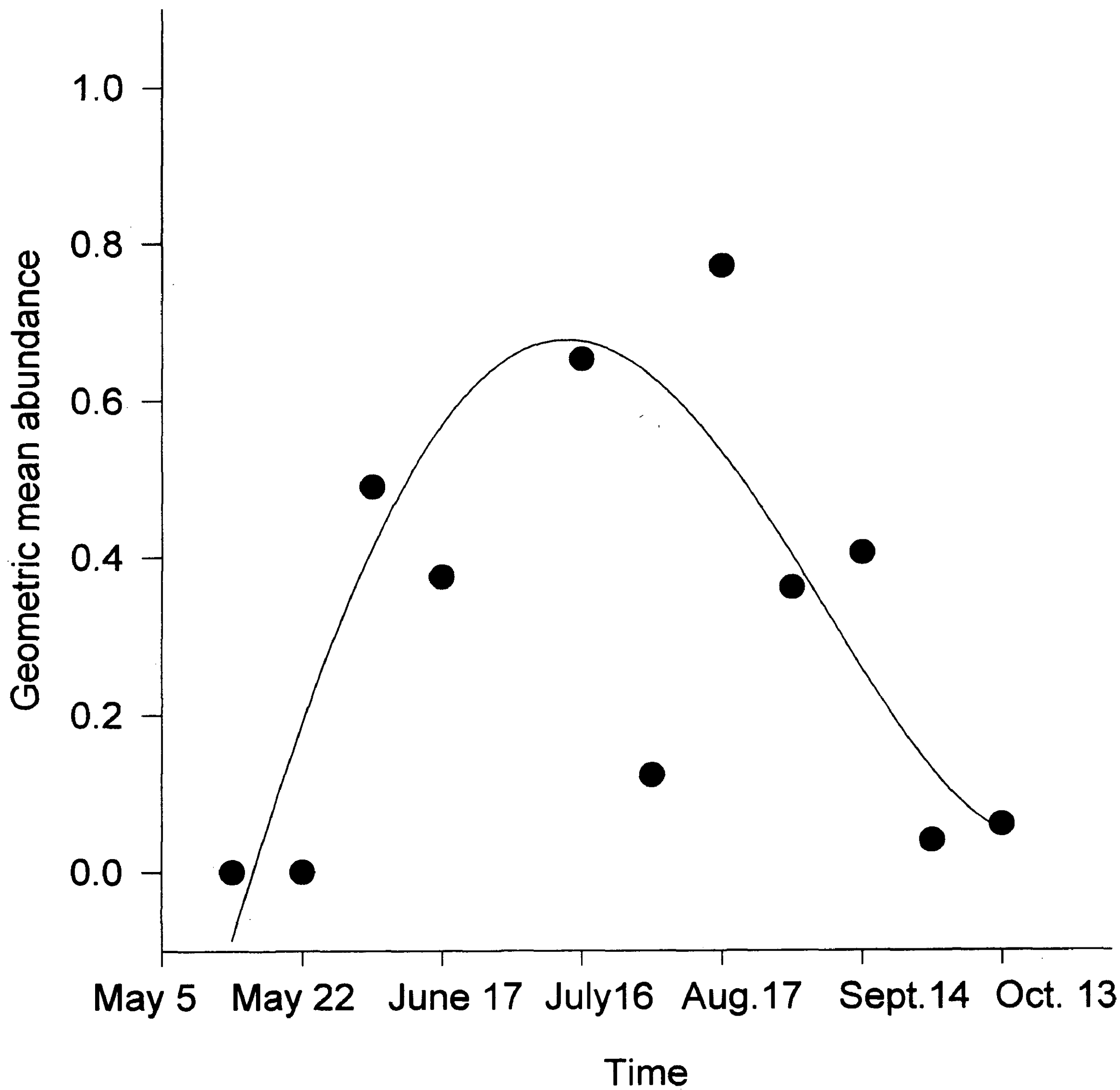


Figure 15. Atlantic menhaden abundance within a season

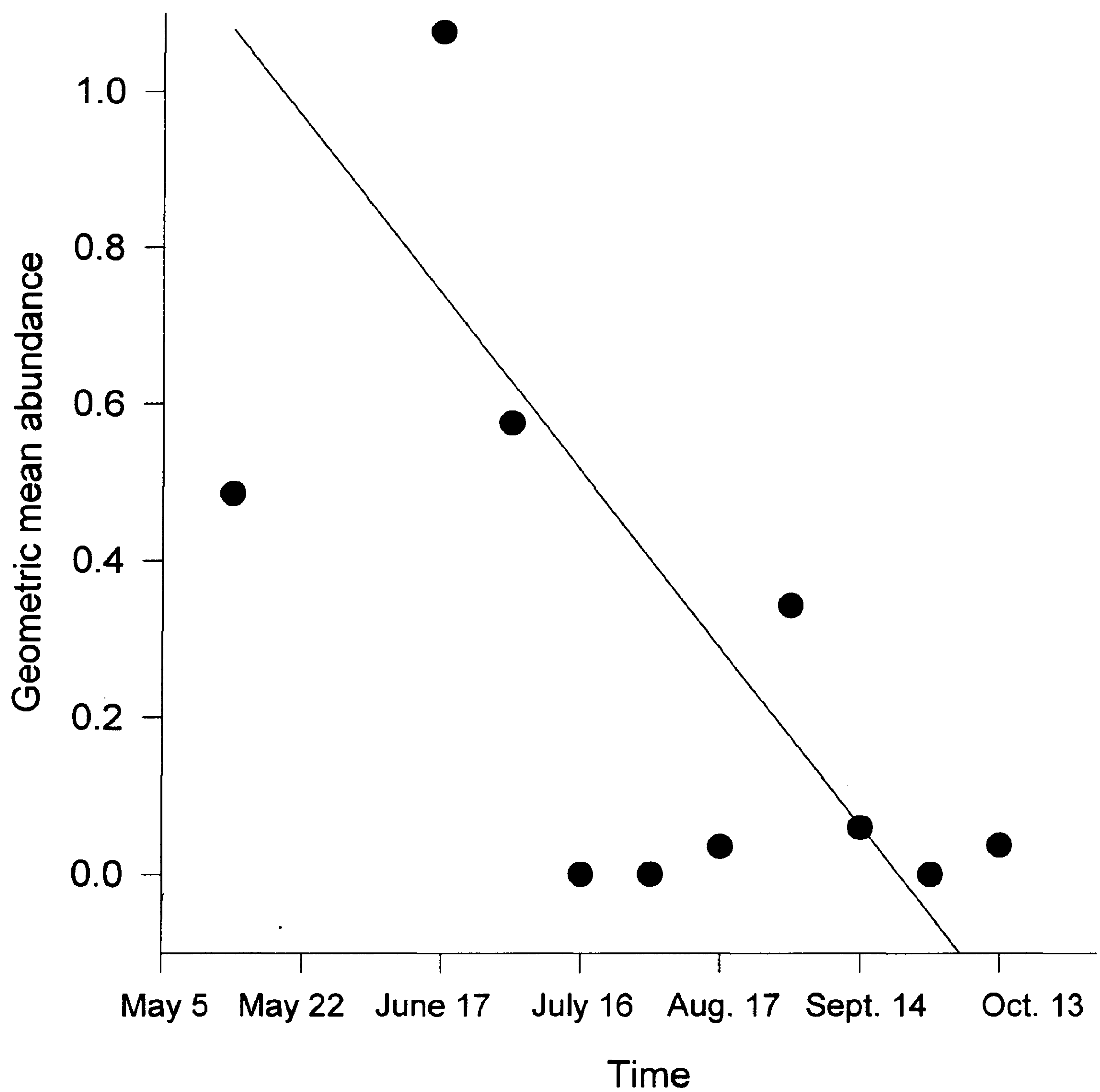
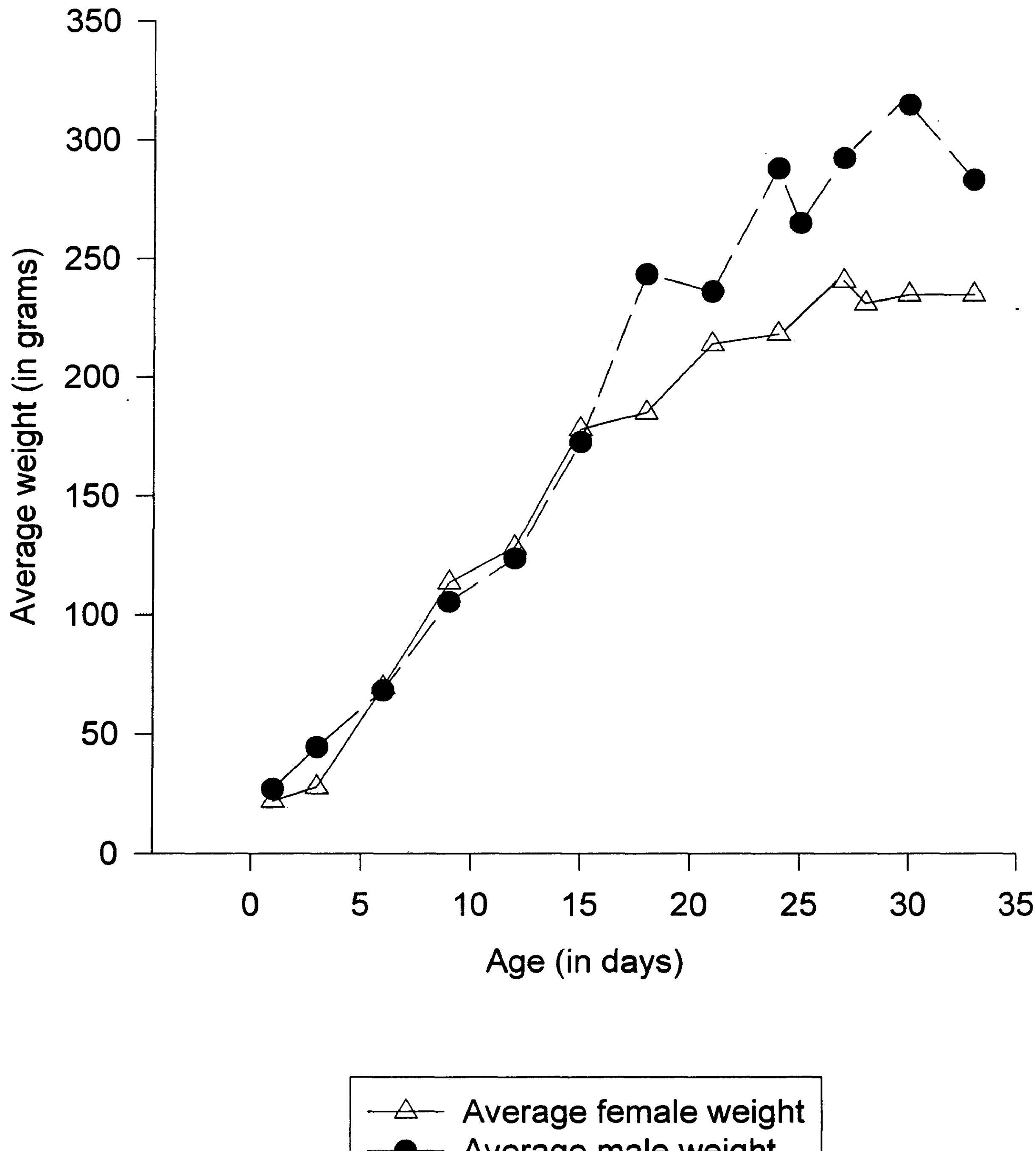


Figure 16. Weight gain measured in young skimmer chicks. All male (n=10) and female (n=12) young fledged



$F_{1, 11}$ =107.46, p=0.0001). The growth constant *K*, calculated separately for each sex, indicates that males have a higher rate of growth (*K*=0.1968) than females (*K*=0.1736).

Prey Length and Biomass

Mean length of prey items returned during the day was 5.97$\pm$2.67 cm, while at night mean length was 9.40$\pm$3.15 cm. Young were fed significantly larger prey items with increasing age at night and during the day (see Table 3; Day observations weighted by sample size: Anova; $F_{2,187}$=6.418, p=0.002; Night observation: t_{405}=-3.716, p=0.0001). Young were also fed significantly larger prey items at night than during the day within the same age group (see Table 3; medium chicks: t_{144} =2.435, p=0.016; large chicks (weighted) t_{877} =2.625, p=0.009). Post hoc multiple comparisons indicated that prey items fed during the day were uniformly smaller than prey fed at night (day<night prey: p=0.0001). Fish collected on the breeding grounds were significantly larger than both day and night prey items (Table 3, Kruskal-Wallis, X^2=218.514, df=2, p=0.0001).

Trends in Fish Abundance and Skimmer Adult Populations

Since 1975, breeding bird surveys on the eastern shore have monitored the population numbers of adult shorebirds each summer (Williams et al. 1990). This survey provides a consistent measure of adult beach nesting shorebirds and can be used to track trends in population status (Williams et al. 1990). The Maryland Department of Natural Resources (since 1959) and the Virginia Institute of Marine Science (since 1968) have monitored long term population trends of fish in the Virginia and Maryland portions of Chesapeake Bay (Austin 1999). When abundance of Atlantic needlefish and menhaden (primary prey items of skimmers at HRBT) are used to explain variance in skimmer

Table 3a. Estimated size (mean cm ± 1S.D.) and calculated biomass of prey items returned to small, medium, and large young during the day and evening.

Fish Observations		Chick Size: Small (0-6 days)	Medium (7-13 days)	Large (>14 days)	Grand Mean
Day Estimate	mean length	N=121 fish 5.66±2.54	N=27 fish 6.95 ± 2.87	N=5 fish 7.62 ± 2.90	N=153 fish 5.97 ± 2.67
	calculated biomass	0.88	2.08	2.71	1.17
Night Estimate	mean length	0 observations	N=119 fish 8.51 ± 3.02	N=288 fish 9.78 ± 3.15	N=407 fish 9.40 ± 3.15
	calculated biomass	0 observations	3.54	4.73	4.37

Table 3b. Summary of estimated length of prey items (mean cm ± S.D.) and calculated biomass (in grams) observed returned to the nest during the day, night, and collected on the breeding grounds.

Fish Observations		Grand mean
Day and night	mean length	n = 560 fish 8.47 ± 3.41
	calculated biomass	3.50
Dropped	mean length	N = 268 fish 14.65 ± 7.46
	calculated biomass	9.28
Day, night and dropped	mean length	N = 828 fish 10.47 ± 5.8
	calculated biomass	5.37

populations on the eastern shore (Fig. 17 and 18), the relationship is highly significant (Figure 19; r^2=0.60, $F_{1,22}$ = 32.3, p=0.0001).

Groundtruthing

Visual estimates of total fish length using binoculars and a spotting scope significantly predicted actual size (binoculars @ 50m; r^2=0.76, $F_{1,23}$=70.28, p=0.0001; spotting scope @ 50m; r^2=0.819, $F_{1,23}$=103.75, p=0.0001, binoculars @ 20m; r^2=0.796, $F_{1,23}$=89.63, p=0.0001). Estimates correctly predicted actual values approximately 75% of the time. See Appendix C for methods and actual values.

Figure 17. Trends in adult skimmer populations and Atlantic needlefish

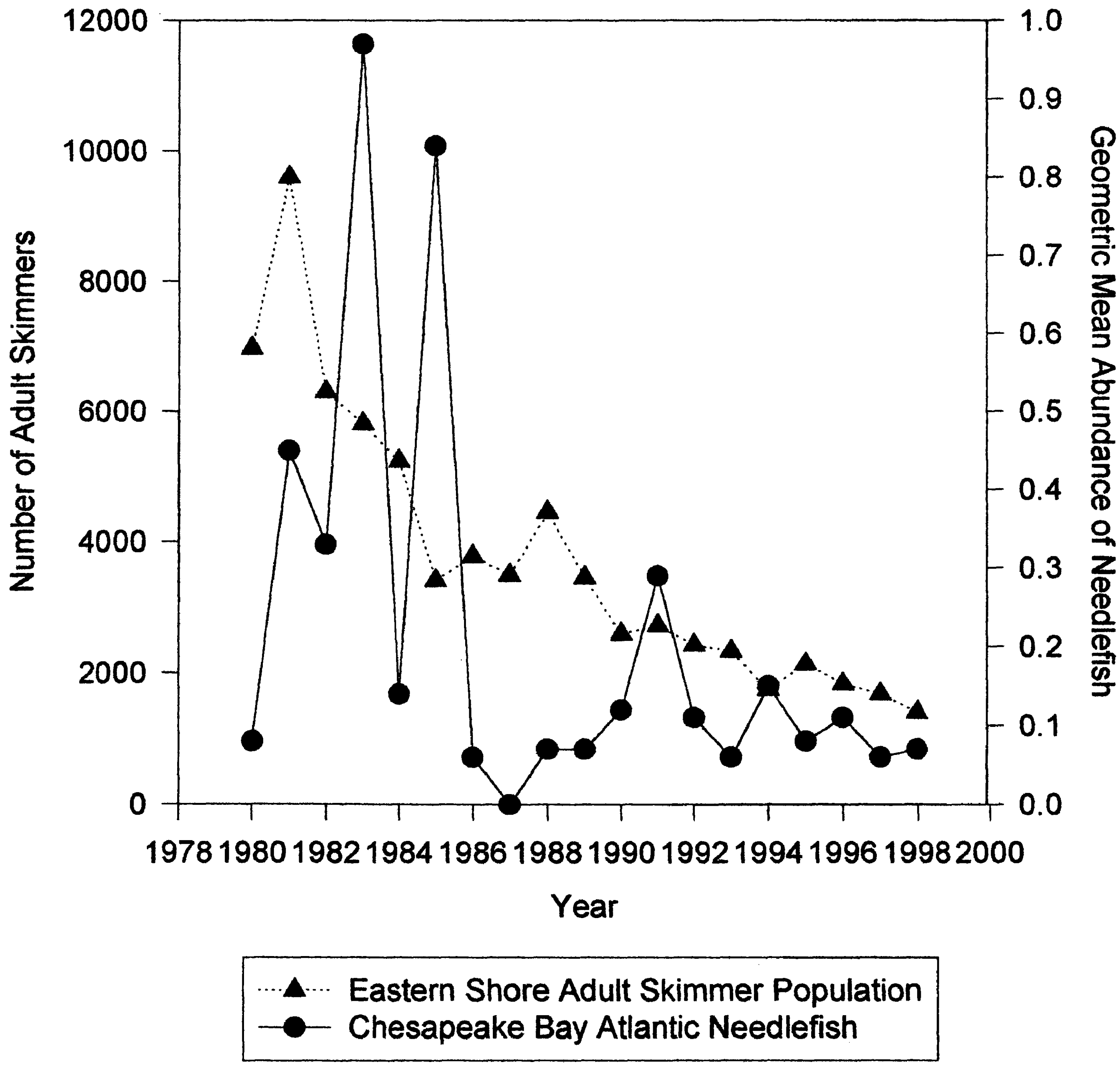


Figure 18. Trends in adult skimmer population and menhaden

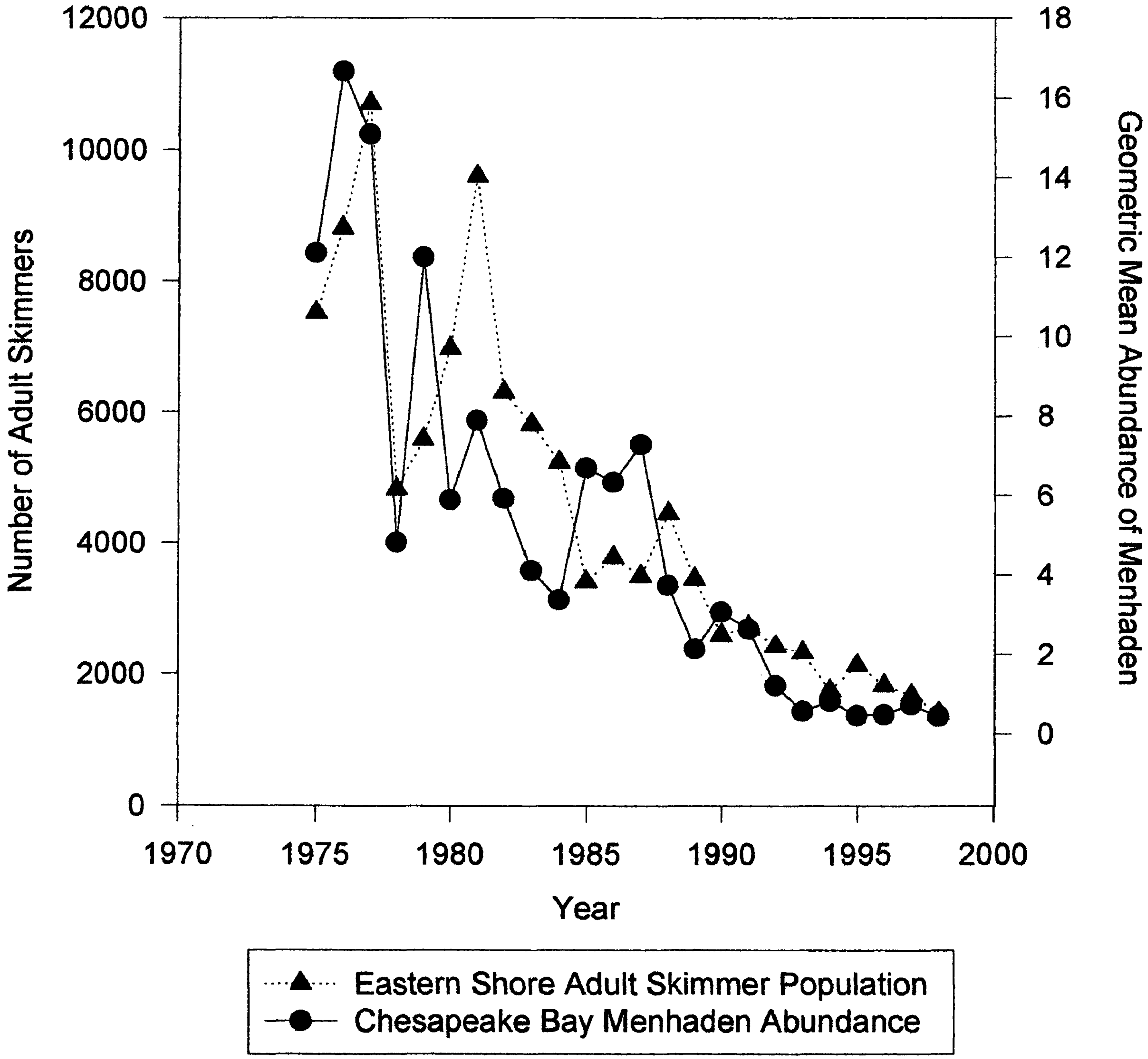
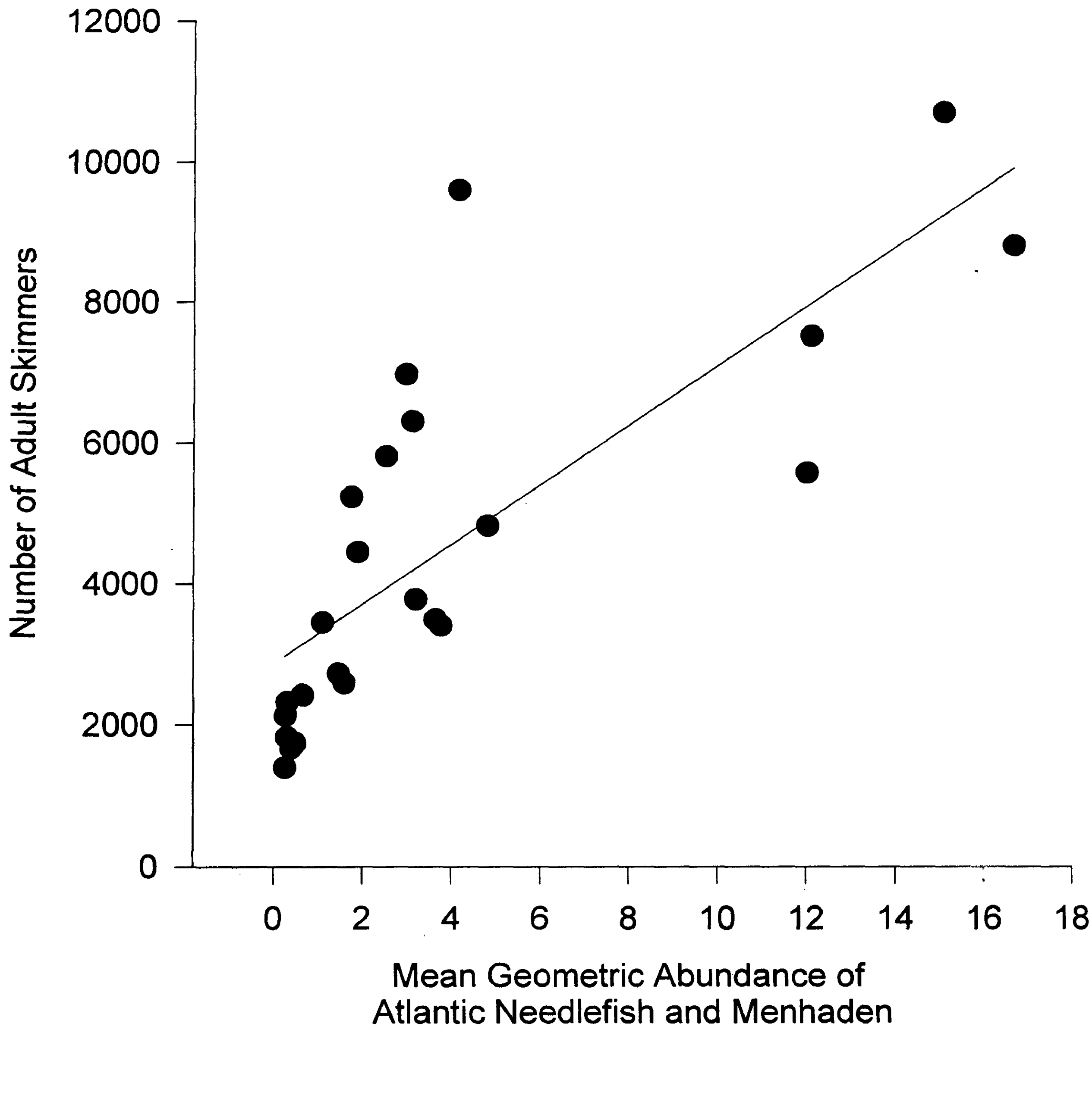


Figure 19. Relationship between Chesapeake Bay Atlantic needlefish, menhaden, and adult skimmers



DISCUSSION

Reproductive Success: Egg, Hatching, and Fledging Success

Despite a near-complete absence of predation and flooding on hatched young, reproductive success was low compared to colonies at natural sites. Mortality was higher during the prefledging period than during incubation, consistent with the hypothesis that parents were unable to provide sufficient food. Several studies have indicated that declining food resources during the breeding season limit fledging success of skimmers (Erwin 1977, Mathews 1995). In Virginia, seasonal declines in Atlantic needlefish and menhaden, the primary food of skimmers at HRBT, support this hypothesis. While the absolute number of young fledging does decline within a season, this more than likely reflects the lower number of eggs being laid and hatched during the breeding season. However, while the absolute number of young fledglings declines, the proportion of young fledged per nest remains relatively constant. If food limits fledging success, the effects of declining food resources are more than likely mitigated by parental effort.

Mean Feeding Rate

Feeding rate was approximately three times higher at night than during the day. Where food deliveries were sampled during the day, the observed feeding rate of 0.075 ± 0.06 fish/hour/nestling appears to be much lower than the mean feeding rate of skimmers sampled both by Erwin on Virginia's eastern shore (1977; 0.149 fish/young/hour) or Burger in West End, New York (1990, 3.87 fish/young/hour) although statistical comparison was not possible. Fish returned to the nest at HRBT during the day (5.97 ± 2.97cm) were smaller than fish measured by Burger (1990; 8.5 $\pm$

2.0 cm) but compare with Erwin's measurements on Virginia's eastern shore (1977; 5.0 cm).

Feeding Rate and Reproductive Success

Parents that fed young more at night fledged significantly more young per nest, while the data from daytime rates indicate a non-significant trend in the same direction. At those nests where both day and night feeding rates were sampled, these figures were highly correlated, and parents which fed young more also fledged more young per nest.

Survival, Reproductive Success, and Date

Despite the influence of date on clutch size and hatching success, fledging success remained relatively constant throughout the breeding season. Hatch order, however, did influence fledging success. First hatched young lived, on average, almost twice as long as second hatched chicks and three times as long as third hatched chicks, and first hatched young were significantly more likely to fledge.

Prey Size and Biomass

Parents fed older young larger prey items. In addition, prey brought back at night were larger than those brought back during the day. This could have resulted from differences in lighting conditions, but studies of skimmer foraging behavior in California have shown that different prey items become available with the onset of darkness (Wilson 1995). In Virginia, seine surveys conducted over a 24 hour period indicated that small fish inhabited the surf-zone, where skimmers forage during the day, while larger fish moved in at night (Austin et al. 1997).

Prey collected on the breeding grounds were uniformly larger than prey delivered at night and during the day. Studies of prey items collected on common tern and least tern breeding grounds have shown that while fish collections might over-represent certain species due to excessive size, collection of dropped prey did indicate the primary fish species eaten by birds (Atwood and Kelly 1984). However, prey collections are not accurate predictors of the size of prey eaten since most dropped fish represented items too large for young (Atwood and Kelly 1984). Observations of fish fed to young and collected on skimmer breeding grounds in California also indicated the same relationship between observed food delivery and prey collections (Wilson 1995).

Trends in Fish Abundance and Skimmer Adult Populations

Temporal trends in Atlantic needlefish and menhaden abundance were significantly correlated with population declines in skimmer numbers on the Eastern Shore. All three species have experienced approximately an 80% decline in population numbers since the early 1980's.

Growth Rates of Young

Skimmer young exhibit sexual size dimorphism and could be distinguished on the basis of weight after approximately fifteen days. Males fledged at a mean of 305g while females fledged at a mean of 243g at HRBT. This is comparable to mean fledge weights recorded in Virginia by Erwin in 1977 (males=295.2g; females=264.4g). However, mean fledge weights from both studies appear to be qualitatively lower than fledge weights observed by Schew and Collins (1990) in California (males = 366g; females = 271g). Collins speculated that yearly variation in food resources could account for differential fledge weights. However the growth rate constants, as measured by *K*, observed in California (males=0.274; females=0.289, Schew and Collins 1990) and Virginia (averaged male and female rate =0.228, Erwin 1977) are both qualitatively higher than growth rates measured at HRBT (males=0.1968; females=0.1736).

Reproductive Success, Date, and Parental Quality

Two primary hypotheses have been advanced to explain differential reproductive success within a breeding season (Brinkhof et al. 1993). The date hypothesis suggests that variation in the environment (i.e. seasonally declining food availability) affects all individuals equally and results in differential reproductive success throughout time. The parental quality hypothesis suggests that variation in parental ability to raise young results in declining reproductive success throughout time as lower quality parents nest later (i.e. inexperienced adults, first time breeders). These hypotheses have been used to interpret reproductive declines across a season (Price et al. 1988).

While evidence supporting both hypotheses exists, the hypotheses are not mutually exclusive (Brinkhof, et al. 1993, Ens et al. 1992). If seasonal variation affects the reproductive success of all individuals equally (date hypothesis), then parental ability to compensate for unfavorable environmental variation could mitigate seasonal effects and create differential reproductive success (Brouwer, et al. 1995). Assuming that variation in parental care has always been a factor in determining reproductive success, it becomes important to identify factors that might explain seasonal declines relative to date effect. If food resources vary within a season, then birds which optimize hatching of young to coincide with periods of high food availability will likely be more successful. However if distance to food is far, or fish scarce, then adults may not be able to adequately provision young. At HRBT, where predation is virtually non-existent, observable disease and parasite problems are minimal, and breeding grounds are protected by breakwater, starvation due to declining food resources and parental ability to forage efficiently and effectively emerge as the likely candidates for determining fledging success.

CONCLUSION

Since longitudinal surveys of colonial waterbirds were initiated in 1975 on Virginia's eastern shore, the number of adult skimmers has declined over 80% in 23 years (Williams et al. 1990, 1998). Several reasons have been suggested for this decline including exposure to increased predation pressure and geographic redistribution (Williams et al., 1990). Invasion of the barrier islands on the eastern shore by fox (*Vulpes fulva*) and raccoon (*Procyon lotor*) resulting in increased predation has been implicated in decreased productivity (B. Watts, pers. comm.). Alternatively, stable numbers of skimmers at HRBT since 1989 would seem to suggest geographic redistribution in accordance with the "distant magnet" hypothesis (Gawlik, et al. 1998). This hypothesis suggests that birds migrate to alternative areas in response to favorable conditions elsewhere. However, despite apparent favorable conditions at HRBT, reproductive success here falls short of natural colonies.

Since the probability of young fledging remains relatively constant throughout the breeding season (i.e. only first hatched) and parental ability to feed young affects the proportion of nestlings to fledge, it would seem that parental quality, as measured by feeding rate, is an important predictor of reproductive success. However, it is important to note that parental quality alone does not determine feeding rate as food availability and other environmental factors more than likely determine feeding rate as well.

Observations of skimmer activity on the breeding ground indicate that adults did not forage near the island (R. Beck, pers. comm.). Seine surveys which sampled fish abundance at stations near HRBT (<1.0 km away) indicated low numbers and diversity of forage fish in 1998 (Austin, 1998). During daytime hourly sampling of feeding rate, foraging adults usually stayed away for over an hour while fishing. As feeding rate affects the proportion of young to fledge from a nest, parental ability to successfully and efficiently forage could mitigate seasonal food declines. However, if distance to food resources is far, constraints on skimmer foraging behavior (i.e. adults return to the nest with only one fish) will limit the number of young fledged per nest. First-hatched young will have a greater advantage and be able to outcompete younger siblings for food.

Along the east and gulf coast, the skimmer is ranked as critically imperiled, threatened, or rare in its breeding range (state ranks listed by Nature Conservancy in New Jersey, Delaware, Maryland, Virginia, North Carolina, Georgia, Florida, and Alabama). Declining numbers along the coast have prompted action in most states, however the skimmer is not listed nor is it currently being considered for addition to the federal list of endangered or threatened wildlife (U.S. Fish and Wildlife, 1998). In Virginia, while the precarious status of the skimmer is recognized by biologists, it is not listed as threatened nor is it listed as a species of concern. As the decline in adult skimmer numbers in Virginia has paralleled the decline in menhaden and Atlantic needlefish in the last 23 years, the determination of factors that affect reproductive success is critical if management strategies to counter current trends are to be developed. As human expansion and development will likely continue to displace shorebirds from their natural habitat, alternative breeding sites will become increasingly important. At HRBT, an alternative breeding site where characteristics favorable for skimmer breeding exist, reproductive success falls short of colonies at natural locations.

APPENDIX A

Using Fish Fragments to Extrapolate Whole Fish Length

To establish the diet of the skimmer, fish fragments as well as whole fish were collected. Partial fish fragments included jaw bones (i.e. needlefish), or head and tail fragments. Since 72% of the skimmer diet consisted of Atlantic needlefish and menhaden, linear regression used to extrapolate whole fish length was restricted to these two species. Linear regression of partial body lengths (i.e. snout tip to end of operculum) to total length was used to develop regression equations (Wilson, 1995). Whole fish caught during the 1998 Juvenile Striped Bass Beach Seine Survey and the Bluefish Seine Survey were used to develop regression equations. Included in the table are the regression equations used to determine whole body length.

The regression equation created from maxilla measurements of Atlantic needlefish was used to extrapolate whole fish lengths for 38 upper beaks recovered. Mandible measurements of Atlantic needlefish were used to estimate whole fish lengths of 75 lower beaks recovered. Head length measurements (from snout tip to end of operculum) of menhaden were used to estimate whole fish length of six head fragments collected.

Table 1. Regression equations used to extrapolate total length of Atlantic Needlefish and Menhaden.

Measurement	r^2, F, p	Linear Equation
Atlantic Needlefish		
Maxilla length (N=29)	r^2=0.944, $F_{1,27}$=457.8, p=0.00001	Y = (4.26)X – 1.745
Mandible length (N=30)	r^2=0.936, $F_{1,28}$=411.1, p=0.00001	Y = (3.78)X – 10.04
Atlantic Menhaden (N=25)		
Snout tip to end of operculum	r^2=0.534, $F_{1,23}$=26.33, p=0.0001	Y = (19.98)X + 2.11

APPENDIX B

Table 1. List of all fish collected at skimmer colony at HRBT during summer 1998. Habitat and migratory-resident status from Fishes of Chesapeake Bay (Murdy, Birdsong, Musick 1997).

Common Name	Scientific Name	Family	Habitat/ Migrant-Resident
American Halfbeak	*Hyporhamphus meeki*	Hemirhamphidae	Marine/migrant
Atlantic Croaker	*Micropogonias undulatus*	Sciaenidae	Estuarine-Freshwater/ Migrant
Atlantic Menhaden	*Brevoortia tyrannus*	Clupeidae	Freshwater-Estuarine/ Migrant
Atlantic Needlefish	*Strongylura marina*	Belonidae	Marine/migrant
Bay Anchovy	*Anchoa mitchilli*	Engraulidae	Marine/resident
Butterfish	*Peprilus triacanthus*	Stromateidae	Marine/migrant
Hogchoker	*Trinectes maculatus*	Achiridae	Marine-Estuarine/ Resident
Lined Seahorse	*Hippocampus erectus*	Syngnathidae	Estuarine/ resident
Mummichog	*Fundulus heteroclitus*	Cyprinodontidae	Freshwater-Estuarine/ Resident
Northern Pipefish	*Syngnathus fuscus*	Syngnathidae	Marine-Estuarine/ Resident
Northern Searobin	*Prionotus carolinus*	Triglidae	Marine/migrant
Sheepshead Minnow	*Cyprinodon variegatus*	Cyprinodontidae	Estuarine/resident
Spot	*Leiostomus xanthurus*	Sciaenidae	Estuarine/migrant
Striped Anchovy	*Anchoa hepsetus*	Engraulidae	Marine/migrant
Striped Killifish	*Fundulus majalis*	Cyprinodontidae	Marine/resident
White Mullet	*Mugil cerema*	Mugilidae	Estuarine/migrant

APPENDIX C

Groundtruthing

In order to determine if visual observation of fish length correlated with actual size, estimates of fish size were used to predict actual lengths (Loeffler 1995, Wilson 1995). Using 10x binoculars and a 15x spotting scope during the day, visual size observations were made from a rooftop on 25 fish at distances of 20m and 50m. These distances were chosen because they represented the nearest (@ 20m) and farthest (@50m) plots where feeding observations were made. The spotting scope was used only to estimate size at 50m since binoculars were used exclusively to estimate size at 20m distances. After estimation of fish size was made to the nearest inch, the actual size of the fish was measured to the nearest 0.1cm. Estimations of fish size were used to predict actual length of fish using linear regression. Prey items presented for estimation were representative of fish collected on the breeding ground in 1998. Included are the species presented, actual size, estimated size, distance at which observation was made, and binocular or spotting scope used to estimate size.

Table 1. Groundtruthing to determine accuracy of estimations. All estimations were made on September 15, 1998. Size estimated to the nearest inch. Visual estimation using binoculars at a distance of 50m.

Species Presented	Actual Size		Estimated Size	
	English (inch)	Metric (cm)	English (inch)	Metric (cm)
Atlantic Needlefish	13.97	35.48	6	15.24
Halfbeak	5.62	14.27	4	10.16
Mummichog	2.36	5.99	1	2.54
Menhaden	3.56	9.04	4	10.16
White Mullet	5.26	13.36	5	12.7
Croaker	4.49	11.40	4	10.16
Hogchoker	3.38	8.59	3	7.62
Mummichog	2.60	6.60	4	10.16
Lined Seahorse	2.16	5.49	2	5.08
Mummichog	3.03	7.70	3	7.62
Sheepshead Minnow	1.57	3.99	1	2.54
Northern Searobin	1.97	5.00	2	5.08
Menhaden	1.18	3.00	3	7.62
Mummichog	2.01	5.11	3	7.62
Striped Killifish	3.31	8.41	4	10.16
Bay Anchovy	1.97	5.00	1	2.54
Butterfish	2.20	5.59	2	5.08
Atlantic Needlefish	6.22	15.80	3	7.62
Northern Pipefish	6.81	17.30	5	12.17
Atlantic Needlefish	10.24	26.01	8	20.32
Atlantic Needlefish	11.02	27.99	8	20.32
Atlantic Needlefish	12.60	32.00	8	20.32
Menhaden	3.62	9.19	3	7.62
Menhaden	3.74	9.50	4	10.16
Menhaden	3.70	9.40	3	7.62

Mean Size Difference: 1.65 cm

Standard Deviation: 2.68 cm

Linear Regression: r^2=0.76, $F_{1,23}$=70.28, p=0.0001

Table 2. Groundtruthing to determine accuracy of measurements. All estimations were made September 15, 1998. Size estimated to the nearest inch. Visual estimation using 15x spotting scope at a distance of 50m.

Species Presented	Actual Size		Estimated Size	
	English (inch)	Metric (cm)	English (inch)	Metric (cm)
Atlantic Needlefish	13.97	35.48	7	17.78
Halfbeak	5.62	14.27	4	10.16
Mummichog	2.36	5.99	1	2.54
Menhaden	3.56	9.04	4	10.16
White Mullet	5.26	13.36	5	12.7
Croaker	4.49	11.40	4	10.16
Hogchoker	3.38	8.59	3	7.62
Mummichog	2.60	6.60	3	7.62
Lined Seahorse	2.16	5.49	3	7.62
Mummichog	3.03	7.70	4	10.16
Sheepshead Minnow	1.57	3.99	1	2.54
Northern Searobin	1.97	5.00	2	5.08
Menhaden	1.18	3.00	3	7.62
Mummichog	2.01	5.11	2	5.08
Striped Killifish	3.31	8.41	5	12.7
Bay Anchovy	1.97	5.00	1	2.54
Butterfish	2.20	5.59	2	5.08
Atlantic Needlefish	6.22	15.80	5	12.7
Northern Pipefish	6.81	17.30	6	15.24
Atlantic Needlefish	10.24	26.01	8	20.32
Atlantic Needlefish	11.02	27.99	9	22.86
Atlantic Needlefish	12.60	32.00	9	22.86
Menhaden	3.62	9.19	3	7.62
Menhaden	3.74	9.50	4	10.16
Menhaden	3.70	9.40	3	7.62

Mean Size Difference: 1.26 cm

Standard Deviation: 2.16

Linear Regression: r^2=0.819, $F_{1, 23}$=103.75, p=0.0001

Table 3. Groundtruthing to determine accuracy of measurements. All estimations were made September 15, 1998. Size estimated to the nearest inch. Visual estimation using 10x binoculars at a distance of 20m.

Species Presented	Actual Size		Estimated Size	
	English (inch)	Metric (cm)	English (inch)	Metric (cm)
Atlantic Needlefish	13.97	35.48	8	20.32
Halfbeak	5.62	14.27	4	10.16
Mummichog	2.36	5.99	1	2.54
Menhaden	3.56	9.04	3	7.62
White Mullet	5.26	13.36	5	12.7
Croaker	4.49	11.40	4	10.16
Hogchoker	3.38	8.59	4	10.16
Mummichog	2.60	6.60	3	7.62
Lined Seahorse	2.16	5.49	2	5.08
Mummichog	3.03	7.69	3	7.62
Sheepshead Minnow	1.57	3.99	2	5.08
Northern Searobin	1.97	5.00	1	2.54
Menhaden	1.18	2.99	4	10.16
Mummichog	2.01	5.11	1	2.54
Striped Killifish	3.31	8.41	4	10.16
Bay Anchovy	1.97	5.00	1	2.54
Butterfish	2.20	5.59	1	2.54
Atlantic Needlefish	6.22	15.79	4	10.16
Northern Pipefish	6.81	17.30	5	12.7
Atlantic Needlefish	10.24	26.01	8	20.32
Atlantic Needlefish	11.02	27.99	7	17.78
Atlantic Needlefish	12.60	32.00	7	17.78
Menhaden	3.62	9.19	4	10.16
Menhaden	3.74	9.50	4	10.16
Menhaden	3.70	9.40	3	7.62

Mean Size Difference: 1.95 cm

Standard Deviation: 3.63

Linear Regression: r^2=0.796, $F_{1,23}$=89.63, p=0.0001

LITERATURE CITED

Atwood, J. L., and Kelly, P. R. 1984. Fish dropped on breeding colonies as indicators of least tern food habits. The Wilson Bulletin 96: 34-47.

Austin, H. 1999. Fluctuations in the forage fish base. Virginia Juvenile Finfish Recruitment Monitoring Research. Virginia Institute of Marine Science.

Austin, H. M., Estes, A. D., and Seaver, D.M. 1998. Estimation of juvenile striped bass relative abundance in the Virginia portion of Chesapeake Bay. Annual Progress Report, US Fish and Wildlife Service Sportfish Restoration Project F87R4.

Austin, H.M., Seaver, D. M., and Wagner, C. M. 1997. Monitoring juvenile recreational fishes on the ocean beaches and eastern shore of Virginia with special focus on developing a Bluefish, *Pomatomus saltatrix*, young of the year index in Virginia. Annual Progress Report, Virginia Marine Recreational Advisory Board, RF-96-09.

Austin, H., and Walter, J. F. 1999. Food habits of large striped bass in the lower Chesapeake Bay and its Tributaries: March 1997-May 1998. Marine and Commercial Fisheries Advisory Board, Virginia Marine Resources Commission Project RF-97-08 and CF-97-08.

Blus, L. J., and Stafford, C. J. 1980. Breeding biology and relation of pollutants to black skimmers and gull-billed terns in South Carolina. U. S. Fish and Wildlife Service Special Scientific Report-Wildlife No. 230.

Brinkhof, M. W. J., Cave, A. J., Hage, F. J., and Verhulst, S. 1993. Timing of reproduction and fledging success in the coot, *Fulica atra*: evidence for a causal relationship. Journal of Animal Ecology 62: 577-587.

Brouwer, A., Spaans, A. L., and de Wit, A. A. N. 1995. Survival of herring gull (*Larus argentatus*) chicks: an experimental analysis of the need for early breeding. Ibis 137: 272-278.

Burger, J., Gochfeld, M. 1990. The black skimmer social dynamics of a colonial species. Columbia University Press, New York.

Custer, T. W., and Mitchell, C. A. 1987. Organochlorine contaminants and reproductive success of blackskimmers in south Texas. Journal of Field Ornithology 58: 480-489.

DePue, J. 1974. Nesting and reproduction of the black skimmer (*Rynchops niger niger* L.) on four spoil islands in the Laguna Madre, Texas. M. S. Thesis, Texas A&I University, Kingsville.

Ens, B. J., Kersten, M., Brenninkmeijer, A., and Hulscher, J. B. 1992. Territory quality, parental effort, and reproductive success of oystercatchers (*Haematopus ostralegus*). Journal of Animal Ecology 61: 703-715.

Erwin, R.M. 1977. Black skimmer breeding ecology and behavior. The Auk 94: 709-717.

Fisk, E. 1976. Roof nesting by black skimmers. Florida Field Naturalist 4:15-17.

Gawlik, D. E., Slack, R. D., Thomas, J., A., and Harpole, D. N. 1998. Long-term trends in population and community measures of colonial-nesting waterbirds in Galveston Bay Estuary. Colonial Waterbirds 21: 143-151.

Keller, G. S. 1992. Nesting substrate preference and breeding success of common terns (*Sterna hirundo*) and black skimmers (*Rynchops niger*) on the Hampton Roads Bridge-Tunnel. M. A. Thesis, College of William and Mary.

King, K. A., Custer, T. W., and Quinn, J. S. 1991. Effects of mercury, selenium, and organochlorine contaminants on reproduction of Forster's terns and black skimmers nesting in a contaminated Texas Bay. Archives of Environmental Contamination and Toxicology 20: 32-40.

King, K., and Krynitsky, A. J. 1986. Population trends, reproductive success, and organochlorine chemical contaminants in waterbirds nesting in Galveston Bay, Texas. Archives of Environmental Contamination and Toxicology 15: 367-376.

Loeffler, W. E. 1995. Dietary overlap and its implications for coexistence in a recently Established assemblage of nesting seabirds at Bolsa Chica Ecological Reserve. M. A. Thesis, California State University, Fullerton.

Mathews, C. D. 1995. Effects of substrate on hatching success in black skimmers, *Rynchops niger*, at the Hampton Roads Bridge-Tunnel, Hampton, Virginia. M. A. Thesis, College of William and Mary.

Mayfield, H. 1961. Nesting success calculated from exposure. The Wilson Bulletin 73: 255-262.

Mayfield, H. 1975. Suggestions for calculating nest success. The Wilson Bulletin 87: 456-466.

Murdy, E. O., Birdsong, R. S., and Musick, J. A. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press. Washington, D. C.

O'Connell, T.J. 1992. The effects of gull predation on the colony reproductive success of terns and and skimmers in Virginia. M. A. Thesis, College of William and Mary.

Price, T., Kirkpatrick, M., and Arnold, S.J. 1988. Directional selection and the evolutionof breeding date in birds. Science 240: 798-799.

Ricklefs, R. E. 1967. A graphical method of fitting equations to growth curves. Ecology 48 (6): 978-983.

Ricklefs, R. E. 1968. Patterns of growth in birds. The Ibis 110 (4): 419-451.

Safina, C., and Burger, J. 1983. Effects of human disturbance on reproductive success in the black skimmer. The Condor 85: 164-171.

Schaffner, F. C. 1986. Trends in elegant tern and northern anchovy populations in California. The Condor 88: 347-354.

Schew, W. A., and Collins, C. T. 1990. Age and sex determination in black skimmer chicks. Journal of Field Ornithology 61: 174-179.

Smith, D.C. 1982. Reproductive success of common tern (*Sterna hirundo*) and black skimmer (*Rynchops niger*) in different habitats in Virginia. M.A. Thesis, College of William and Mary.

Taylor, M. D. 1997. Demography of the black skimmer (*Rynchops niger*) in Southern California. M. S. Thesis, California State University, Long Beach.

U.S. Fish and Wildlife Service. October 31, 1998. Endangered and threatened wildlife and plants. Code of Federal Regulations 50: 17.11.

White, D. H., Mitchell, C. A., and Swineford, D., M. 1984. Reproductive success of black skimmers in Texas relative to environmental pollutants. Journal of Field Ornithology 55: 18-30.

Williams, B., Akers, B., Beck, M., Beck, R., Via, J. 1998. The 1998 colonial and beach nesting waterbird survey of the Virginia barrier islands. The Raven 70 (1): 15-19.

Williams, B., Beck R., Akers, B., and Via, J.W. 1990. Longitudinal surveys of beach nesting and colonial waterbirds of the Virginia barrier islands. Virginia Journal of Science 41:381-388.

Wilson, J. F. 1995. Diel periodicity and dietary breadth in the black skimmer (*Rynchops niger*), implications for coexistence in a mixed-species colony of breeding seabirds. M. A. Thesis, California State University, Fullerton

VITA

Christopher Alan Gordon was born on September 22, 1974 in Cherry Point, North Carolina. He grew up in North Carolina, Hawaii, and Virginia graduating from Chancellor High School in Fredericksburg, Virginia in 1992. In 1996, he received a B.S. in Biology from the College of William and Mary, Virginia. He entered the College of William and Mary in 1996 as a graduate student in Biology and was a teaching assistant during the 1997-98 school year. In May 1997, he received a grant from the Williamsburg Bird Club, and in April 1998, he attended the American Ornithological Union meeting in St. Louis, Missouri.